Environment

Submitted to:
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Gaithersburg, Maryland 20879

Submitted by:
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Willington, CT
Project 60142744
February 2010

Management of Hydrilla in Swift Creek Reservoir

Chesterfield County, Virginia

Final Report 2/11/10

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1.0 Executive Summary

Invasion of 1700-acre Swift Creek Reservoir by *Hydrilla verticillata* has resulted in substantial coverage of over 700 acres of this water supply and recreational boating waterbody, all in the upstream portion of the northwestern arm of the reservoir at this time. Consideration of expansion potential suggests that about 900 acres might be affected in total, based on light limitation at depths greater than about 9 feet, and that infestation of all possible areas could be expected within a few years. Areas yet to be infested include a narrow shoreline margin and the southwestern arm of the reservoir.

To some extent, hydrilla acts as a sediment filter for inputs to the reservoir, but it also has some potential to add excessive organic matter to the water and foster algal growths that could create taste and odor or even toxicity problems. However, there is no evidence of these impacts at this time. Note that algal toxin concentrations sufficient to harm animals or people are linked to high concentrations of toxic algae not observed in Swift Creek Reservoir to date. Note also that consumption of untreated water represents the primary risk of toxicity; treatment of Swift Creek water to remove any toxins, should they ever be present, is possible with the existing treatment system. The primary current impact is interference with boating use of the reservoir; over 40% of the reservoir area is now affected, and shoreline residents have difficulty reaching open water through dense nearshore growths. Additional impact is expected on the reservoir fish community, as predatory fish will have difficulty foraging in dense hydrilla, resulting in poor growth by gamefish and overpopulation and stunted growth by prey species. This impact may extend to wildlife that depend on fish resources.

Eradication of this invasive plant is extremely difficult, but some level of control is desired to restore and protect the designated uses of the reservoir. A review of specific alternatives for the management of hydrilla is provided, and while no one technique provides all desired benefits with no unwanted side effects, there are several approaches that could yield improved conditions. The"no action" alternative could be considered, but may result in significant impact to boating in the shallower portions of the lake. However, the impact of no action on water quality and treatability is uncertain and may not be substantial. Benthic barriers (sheet materials placed on the reservoir bottom) or mechanical harvesting (cutting and collection of plants) could facilitate boating by creating access or cruising lanes through hydrilla infestations, but do not appear practical or desirable for the entire infested area. Additionally, benthic barrier installation is not compatible with present policies prohibiting human contact in the reservoir. Drawdown (water level lowering), dredging (sediment removal), herbicides (chemicals that kill target plants) and herbivorous (plant-eating) fish represent options for more widespread control in the reservoir, although each has drawbacks.

A more detailed analysis of costs was conducted, as this was considered a primary factor in choosing among applicable alternatives. Combining costs and environmental impacts, alternatives are more fully evaluated. Mechanical harvesting is more expensive than benthic barriers, but a single harvester could address much more area than could the barriers at the projected cost, and with greater flexibility. Additionally, the potential to contract for harvesting services allows this approach to be tested at considerably less initial investment. For localized and more immediate control, a harvesting program is recommended, but this will not meet the anticipated overall need for hydrilla control.

For more widespread control of hydrilla in Swift Creek Reservoir, dredging is most preferable in terms of overall benefits and least unintended environmental consequences, but the cost is extreme, and dredging is still unlikely to control hydrilla in all areas. Drawdown is least expensive, but presents substantial risk of water supply shortages and may not control hydrilla to an acceptable extent. Use of the herbicidal ingredient fluridone could minimize hydrilla coverage, but not indefinitely and at great cost. Also, adding herbicidal chemicals to a water supply creates negative public perceptions that limit the frequency of application in most cases. Use of herbivorous fish has had mixed results, but experience over about two decades of practical application suggests that an acceptable level of control is possible, and that use of sterile grass carp will limit the duration of any impacts (including grazing on macrophytes and any influence on water quality) to the effective lifespan of these fish, typically 5 to 10 years. The primary drawbacks for grass carp include likely loss of most native aquatic plants and increased nutrient availability, possibly leading to more frequent and severe algal blooms in the reservoir and greater cost for water treatment. Yet acceptable control has been achieved in similar reservoir situations, and grass carp represent the least expensive option after drawdown, so this approach is therefore considered the best option at this time for widespread control of hydrilla in Swift Creek Reservoir.

From the full evaluation, a combination of mechanical harvesting and stocking of sterile grass carp is suggested as the most effective, economically favorable, least environmentally damaging approach to controlling hydrilla in Swift Creek Reservoir. Elimination of hydrilla is unlikely, and increased cost to the county water supply utility is expected, either for control of nutrients and algae in the reservoir or increased treatment of raw water at the treatment facility.

The cost of a decade of control by grass carp is estimated at $225,000. The cost of mechanical harvesting as a support system varies with harvester purchase vs. contracted services, and the level of application. Based on stocking grass carp at an appropriate density and operating a harvester on a contract basis for 5 years, after which control of hydrilla by grass carp alone is assumed, a ten-year cost of $425,000 is estimated. If a harvester was purchased and operated by a management group formed for that purpose, more harvesting could be conducted and after five years the harvester would be available for further use or resale, but the cost would rise to at least $700,000. Contracting for harvesting services for at least two years is recommended, followed by an evaluation. It is important to note that these estimates do not include any costs for plant disposal, control of algal blooms or increased treatment needs at the water treatment facility, all possible considerations in this case.

A five year strategy is proposed, including formation of an overall reservoir management organization, operation of a harvester to provide immediate and localized relief from hydrilla impacts, stocking of 8,500 grass carp in the first year to initiate grass carp control throughout the reservoir, and addition of up to another 4,500 fish in the third year, based on monitoring results for plants, fish and algae.

2.0 Introduction and Background

As described in the 2008 hydrologic and water quality data report from the Addison-Evans facility staff, Chesterfield County Utilities and Engineering Staff, and KCI Technologies, Swift Creek Reservoir is a public water supply for Chesterfield County, covering 1700-acres (2.7 square miles) and containing approximately 5.2 billion gallons (16,000 acre-feet) of water. It is located approximately 10 miles southwest of Richmond, Virginia. The watershed for Swift Creek Reservoir covers the northwest part of the county and encompasses 61.9 square miles. The sampling station figure from the report is provided here as Figure 1, providing a spatial reference for additional discussion.

Water quality is considered suitable for the designated uses of the reservoir. While tributary loads of phosphorus can be elevated during storms, inlake levels meet state standards and resultant chlorophyll concentrations are well below the state standard. From Addison-Evans Lab data, the algal community includes mainly chlorophyta (green algae) and chrysophyta (golden algae, including diatoms here), but higher levels of cyanobacteria (blue-greens, mainly *Anabaena*) are encountered in summer. With frequent monitoring, algal levels are kept in check with copper treatments when necessary, and major cyanobacterial blooms have largely been prevented from forming.

Water clarity ranges from 2.0 to 4.5 feet most of the time, with an average near 3.0 feet, which is not especially clear. However, much of the light extinction is related to sediment particulates in the water column, either entering from the watershed with tributary flows or resuspended from the bottom of the reservoir. Average values for total suspended solids at the various monitored stations range from about 2 to 10 mg/L.

From the area and volume, average depth is calculated to be about 9.4 feet. From the water clarity data, light penetration sufficient to grow rooted plants will occur at depths less than about 9 feet. This means that the reservoir is susceptible to plant growths by light penetration to the bottom over a substantial portion of the reservoir.

Inflow in 2008 was about 72,000 ac-ft, but precipitation in 2008 was higher than normal, and a long term annual inflow of about 67,000 ac-ft is suggested. With a volume of 16,000 ac-ft, this translates into a flushing rate of just over once per season, or about 4.2 times per year. Flushing is not even over the course of the year, but at 3+ months of detention time, the reservoir will retain most of the sediment and associated contaminants entering from the watershed.

The watershed has experienced substantial development over the last three decades. There are two large development associations, Brandermill and Woodlake, on opposite sides of the reservoir. Other portions of the watershed have experienced conversion from forest or farm to housing or commercial development. Considering the expected increase in inputs of sediment, nutrients, bacteria, and other contaminants, the reservoir is in a relatively desirable condition. Management is needed, both to maintain designated uses and to prevent further degradation, but conditions linked to water quality are generally acceptable.

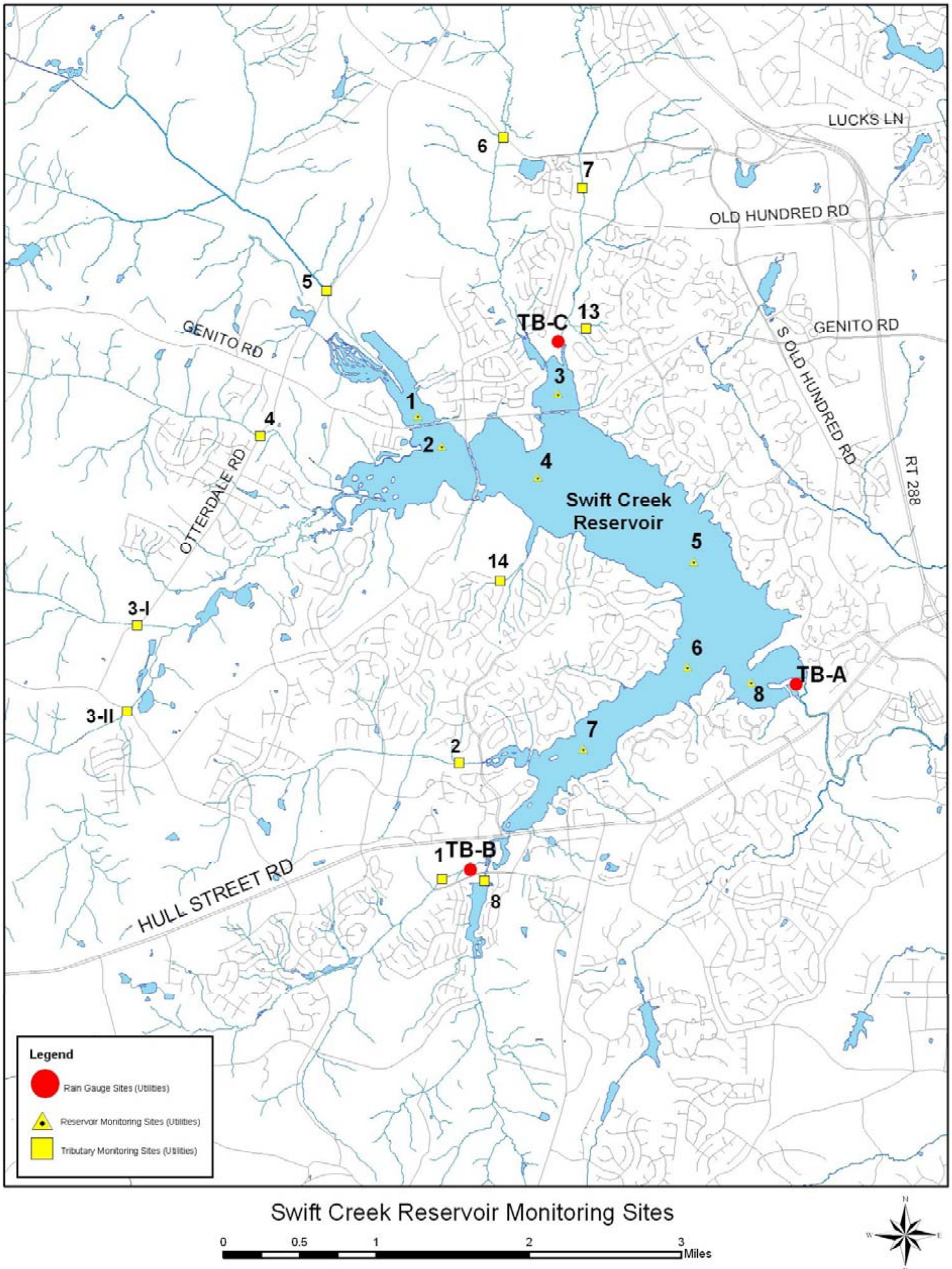

Figure 1. Swift Creek Reservoir and Immediate Vicinity, with Sampling Stations

The uses of the reservoir include mainly water supply, boating and wildlife habitat. Water supply includes up to 12 million gallons per day of water that is withdrawn and treated, based on the 2008 Master Plan for the treatment facility by Black and Veatch. Swimming is prohibited in the reservoir. Boating is with paddle craft, sailboats, and motorized vessels. Electric motors are required for motorized boating, eliminating issues with fuel spillage or emissions for the water supply. Fishing and wildlife viewing are popular pursuits from boats, as well as cruising.

The primary issue facing the reservoir users at this point in time is the recent infestation by *Hydrilla verticillata*, an invasive rooted plant. The precise year of invasion is not known but is believed to be at least two years ago and possibly four to five years ago. Even with regular monitoring, it is difficult to detect submergent invasive plants during the earliest stages of invasion; the density is simply too low and the area to be searched too large. The focus of monitoring can be narrowed somewhat to logical points of entry (boat launches, tributary inlets, and areas of larger congregation by birds), but this still provides no guarantee of early detection. When the infestation is not detected until the invasive species has become established, rapid responses may not be practical. In the case of hydrilla, expansion can be very rapid, negating typical rapid responses within a year or two. This has apparently been the case for Swift Creek Reservoir, and hydrilla now covers over 700 acres of this 1700-acre reservoir, impacting boat traffic, altering habitat, and possibly threatening water quality if there is any significant die-back of plants.

Concern over the hydrilla infestation has prompted Chesterfield County to seek guidance on how best to manage this plant. This report represents an assessment of options based on current conditions and constraints.

3.0 Nature and Extent of Macrophytes in Swift Creek Reservoir

Based on light penetration, rooted plants are expected to grow at water depths of up to 9 feet in Swift Creek Reservoir. This is estimated at either three times the average Secchi depth (3 feet) or from the equation $\text{Log MDC}=0.79 \log SD +0.25$, where MDC = maximum depth of colonization and SD= maximum Secchi depth, both in meters (Hoyer and Canfield 1997). At greater depths, there is not enough light to support early plant growth, although it may be possible for plants to survive if stems can extend to a well-lit area and leaves can be formed there. For the most part, however, dense growths would not be expected in water greater than 9 feet deep.

The portion of the reservoir less than 9 feet deep (about 900 acres) is slightly larger than half the reservoir area. In Figure 2, which color codes depth by relative elevation, the 9 feet water depth contour occurs somewhere in the magenta hue. The current hydrilla infestation, covering approximately 736 acres, is therefore already occupying about 82% of the area it might be expected to occupy. The remaining uninfested area includes a small peripheral fringe in the main body of the reservoir and the upstream third of the southwestern arm of the reservoir. The actual extent of hydrilla infestation is shown in Figures 3 and 4. Figure 4 is based on a hand drawn map from a visual survey in August of 2009, while Figure 3 is based on measurements made in October

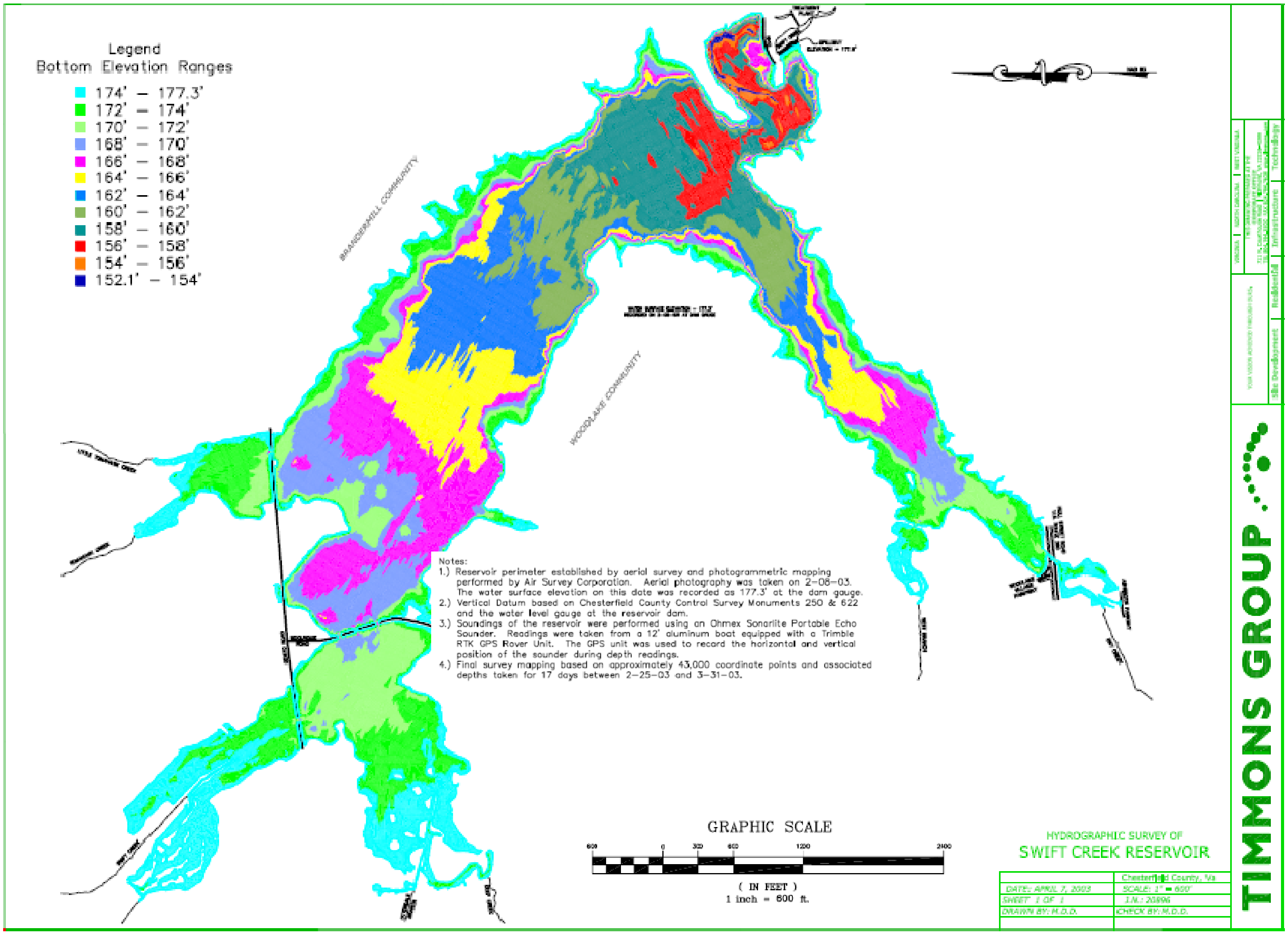

Figure 2. Bathymetry of Swift Creek Reservoir.

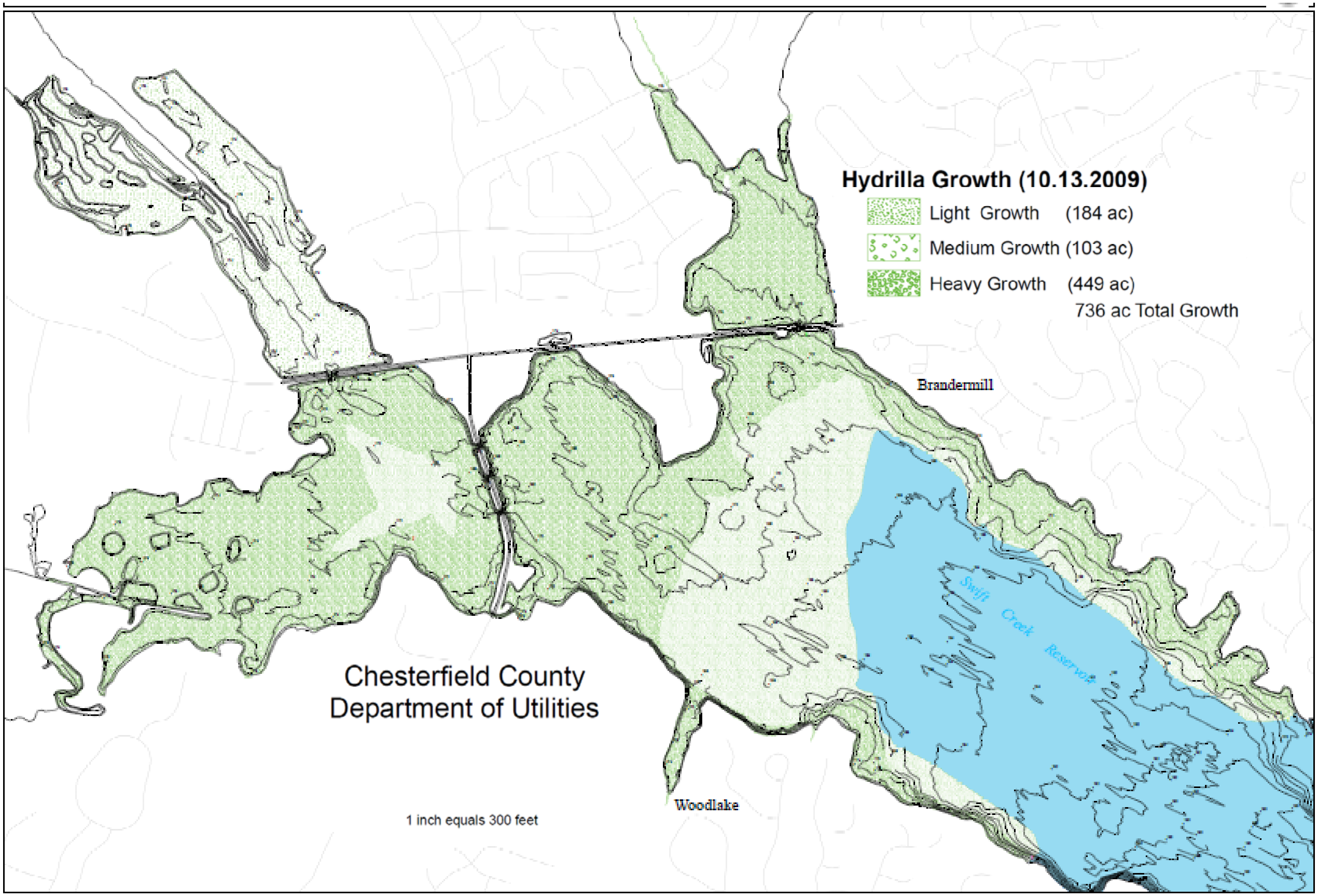

Figure 3. Bathymetry and extent of hydrilla growth in Swift Creek Reservoir in October 2009.

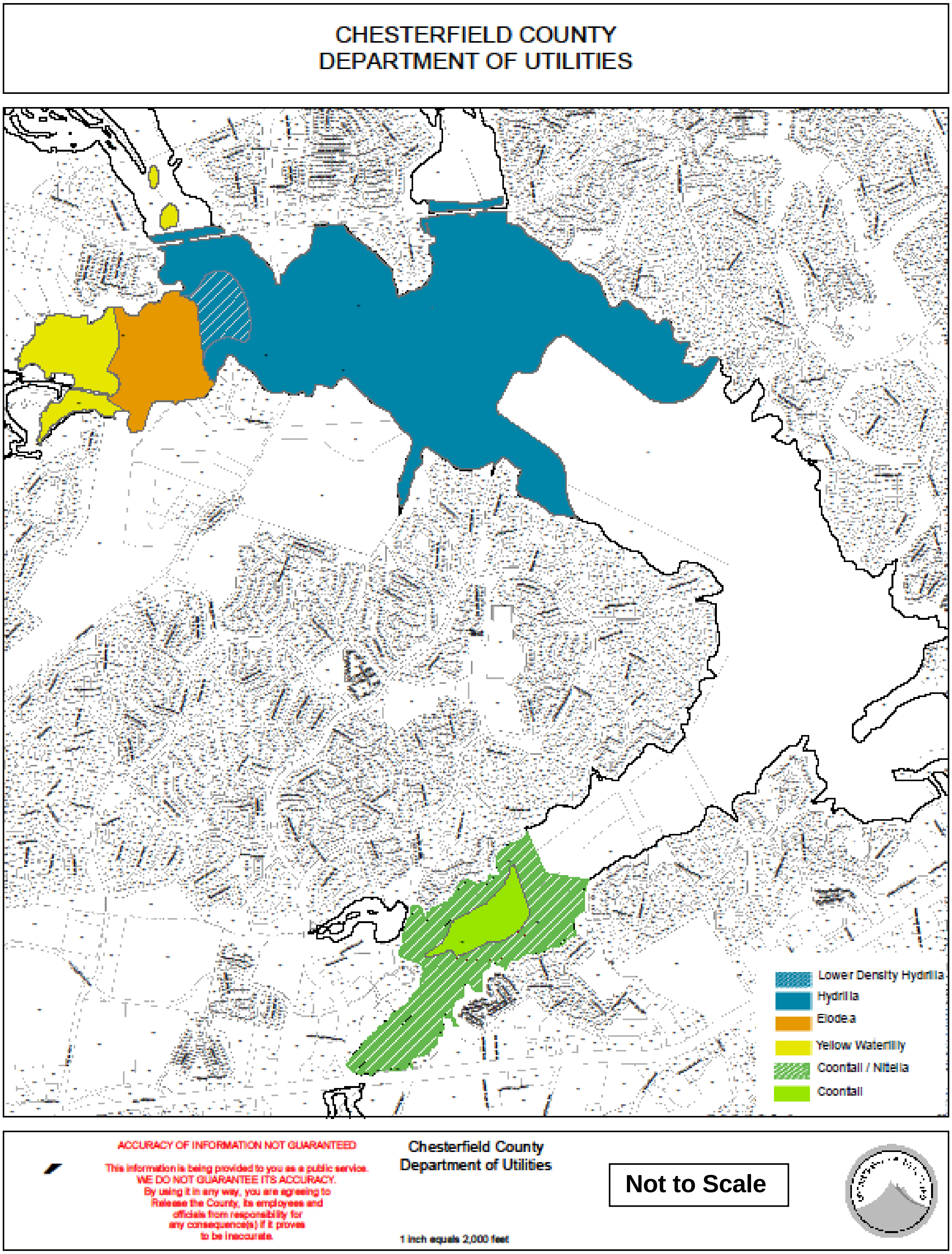

Figure 4. Distribution of Macrophytes in Swift Creek Reservoir in August 2009.

of 2009 and located by GPS. Figure 4 indicates the location of remaining native plant stands, and comparison of the two maps indicates apparent spread of hydrilla over just the two intervening months.

A general survey of the reservoir on November 4, 2009 using an underwater viewing camera confirmed the hydrilla distribution shown in Figure 3. Few growths were found at water depths greater than 8 feet, with no growths deeper than 10 feet. The forebays at the upstream end of the northwestern arm of the reservoir were not examined in detail, and a recent rise in water level provided a small weed-free perimeter, but otherwise the northwestern arm exhibited dense growths between water depths of about 1.5 and 8 feet. Growths extended eastward along the shore as shown in Figure 3, and tapered off in an easterly direction, as water depth increased and subsurface slope from the shore to deeper water increased, especially on the southwest side. It is apparent that growths could continue to expand eastward, but only in a narrow band near the shore, covering few additional acres but impacting shoreline use and boating access in areas not yet infested.

There was no indication of any hydrilla in the southwestern arm of the reservoir in early November of 2009. Given the dominance of water inputs from the northwestern arm, it seems likely that hydrilla fragments would be washed into the southwestern arm during larger storms, when there is an overall water level rise and water from the northwestern arm is likely to back up into the southwestern arm before it can all be passed through the outlet. This may not have occurred during the stormy period just prior to the November 4, 2009 site visit, but is reported to have happened during a later November storm; hydrilla pieces were observed in the southwestern arm by shoreline residents and water treatment facility staff. Invasion of the southwestern arm of Swift Creek Reservoir by hydrilla would seem inevitable.

The native flora of Swift Creek Reservoir includes yellow waterlily (*Nuphar* sp.), coontail (*Ceratophyllum demersum*), waterweed (*Elodea Canadensis*) and nitella (*Nitella flexilis*), based on recent surveys (Figure 4). Each of these species except yellow waterlily was observed during the November 4, 2009 site visit, but none was particularly abundant. In areas where hydrilla was dominant, very few other plants were found, consistent with what has been observed in other infested reservoirs. Three native species were observed in the southwestern arm, where no hydrilla was yet present, but some nitella was also found intermingled with hydrilla in the deepest areas where plants were found in the northwestern arm. Yellow waterlily is confined mainly to the forebays at the upstream end of the northwestern arm. With continued hydrilla expansion and establishment, leading to dense canopy formation during summer, native species will be reduced in abundance or even eliminated by a lack of light.

4.0 Implications of Hydrilla for Reservoir Management

Hydrilla grows very densely, shading out other plants and providing limited habitat for most desirable aquatic organisms. Impairment of virtually all recreational activities is to be expected. Sometimes fishing improves for those trolling along the deepside edge of an infestation, but only when there is enough unimpacted area that the plants represent valuable structure in an otherwise featureless water mass. Hydrilla is a difficult plant to manage, as a function of its general ecology and varied reproductive strategies. Key hydrilla features are summarized in the rapid response plan for hydrilla prepared by ENSR (now part of AECOM) for the Massachusetts Department of Conservation and Recreation in 2005:

> *Hydrilla verticillata* (hydrilla) is a submerged aquatic perennial plant. The roots of hydrilla are long and thin, typically whitish to light brown in color. Roots are usually buried in the hydrosoil, but may form adventitiously at the nodes. Stems are ascending and heavily branched near the water surface, and horizontal and creeping under the soil. Stems of hydrilla can reach a length of 8.5 meters (m). Turions are formed infrequently in the axils of the leaves on the upper part of the stem, and on subsoil stolons. Leaves are narrow, 1-2 centimeters (cm) (0.4-0.8 inches) long, and whorled around the stem in groups of 4-8. On the lower stem, leaves may be opposite in arrangement. The leaf margins are serrated, visibly to the naked eye. Flowers are unisexual, less than 6 mm in diameter, and translucent to white in color. Two biotypes of hydrilla plants occur, dioecious and monecious. Flowers of only one sex are produced on dioecious plants, while monecious plants produce both male and female flowers. Male flowers grow on a short stalk and are free floating at maturity. Female flowers are composed of six colorless segments, and are 1.2 to 3.0 millimeters (mm) (0.05 to 0.12 inches) long. Fruits of hydrilla are cylindrical in shape, and 5 to 10 mm (0.2-0.4 inches) long.
>
> Hydrilla grows most often in freshwater lakes, ponds, rivers, impoundments, canals and ditches, under a wide range of environmental conditions. It usually grows in shallow waters, but can grow at depths greater than 10 m (33 feet). Hydrilla grows in both acidic and alkaline environments, and at trophic levels ranging from oligotrophic to eutrophic. Although hydrilla grows on all types of substrates, it grows best on sediments with high organic content. Hydrilla is adapted to grow under very low light conditions, and therefore can quickly dominate native vegetation. Hydrilla can also tolerate a wide range of temperatures and is winter-hardy.
>
> Hydrilla is well adapted to rapid spread and growth due to various modes of reproduction. Pollination occurs above the surface of the water and its seeds develop into hypocotyles up to 6 mm (0.25 inches) in length. The hypocotyle produces a short stem at the node along with 3 leaves and a few roots. Hydrilla can also reproduce from rootstocks, turions (both subsoil and on the stem), and vegetative nodes. Entire colonies can be formed from one single node which can produce adventitious roots and quickly spread. A single tuber can produce more than 6,000 new tubers per square meter (10.8 square feet).

We are uncertain whether the *Hydrilla verticillata* in Swift Creek Reservoir is monoecious (only male or female reproductive parts on any given plant) or dioecious (both male and female parts on the same plant); only male flowers were found on any plants. However, this plant does not depend solely on seeds for invasion and expansion, so this distinction may not be critical to management strategy selection. The monoecious form appears to be the one currently colonizing the mid-Atlantic states and New England. Hydrilla in Swift Creek Reservoir does not grow densely at depths greater than 8 feet as a function of light limitation, but can be found as deep as 10 feet. Hydrilla is clearly established, and covers most of the area it might be expected to colonize, although the remaining uninfested area is physically separate (in the southwestern arm). These sorts of assessments feed into a threat analysis, which in turn supports a control evaluation.

While seemingly self-evident, organizing what we know of hydrilla in Swift Creek Reservoir as shown in Table 1 can be useful when considering management options. Clearly the situation is well beyond any rapid response scenario, but conditions in the northwest arm of the reservoir are not likely to get much worse than they are. While open water will remain suitable for boating and fishing, the shallow, nearshore area that is essential to access for these activities will be greatly compromised.

In a manual prepared for the American Water Works Association Research Foundation (AwwaRF) in 2008, Wagner and colleagues describe water quality and related issues for water supplies from invasive species of milfoil (*Myriophyllum*). The same issues (e.g., organic content, associated taste and odor algae, oxygen and/or pH impacts) apply to hydrilla, but that does not mean that related problems will occur in any given reservoir. The large volume of plant material in Swift Creek Reservoir has the potential to impart high organic content to the reservoir water upon death and decay, and may affect oxygen and pH on a lakewide basis, but there is no evidence of such problems currently and the Addison-Evans lab staff has been monitoring with such impacts in mind.

Algal growths associated with hydrilla in Swift Creek Reservoir appear to be largely filamentous green algae with limited impact on taste and odor, and no expected toxicity. The only cyanobacterial mats encountered in November 2009 were in the southwestern arm of the reservoir, where there was no hydrilla. These mats were on bare sediment and were not extensive. Tracking of associated algal growths through an entire year would be necessary to more definitively assess potential impacts from hydrilla on taste, odor and any algal toxicity in Swift Creek Reservoir.

It is possible that large amounts of hydrilla could break free and float in the reservoir, potentially clogging the intake, but that has not yet happened. Also, the physical configuration of the reservoir, with the intake in a side cove near but offline from the outlet suggests a low probability of clogging problems. Conversely, the dense vegetation at the inlet end of the reservoir where the majority of water enters from a substantially developed watershed creates a filter that may actually enhance water quality in terms of suspended solids and particulate contaminants further into the reservoir. Native vegetation such as coontail or waterweed could provide much of the same service in the absence of hydrilla, but have not achieved the density observed for hyrilla in this case.

The effect of hydrilla in Swift Creek Reservoir on water treatment is therefore unclear. The dense growths have the potential to attenuate impacts of turbidity, nutrients, and organics loaded from the watershed, and there is some indication of such an effect during recent storm events. There is a possibility that hydrilla could produce conditions that could require additional water treatment, but such effects have not been observed since hydrilla was detected in the reservoir and the water treatment facility possesses treatment strategies to deal with them if they were to occur. The primary potential adverse impact on water supply appears to be possible increased treatment costs.

Table 1. Threat analysis for hydrilla in Swift Creek Reservoir.

THREAT CATEGORY	SPECIFIC FACTOR	YES	NO	NOTES	HIGH	MED	LOW	UNKNOWN
Extent and speed of possible infestation	Large area could be affected	X		900 out of 1700 ac (now at 736 ac)	X			
	High plant density	X		Already is	X			
	Rapid spread	X		Already is	X			
Nature of possible impacts	Water supply may be impacted	X		Possible DBP issues, but also acts as filter at upstream end of reservoir				X
	Swimming may be impacted		X	No swimming allowed			X	
	Boating may be impacted	X		Limits activity in <8-10 feet of water	X			
	Fishing may be impacted	X		Very hard to fish in hydrilla		X		
	Aesthetics may be impacted	X		Generally unappealing, but vistas and reflections will remain		X		
	Sensitive species may be impacted	X		Wildlife may have trouble accessing fish	X			
Ability to spread	Spread by water flow likely	X		Observed movement after storm	X			
	Spread by birds likely		X	Low probability			X	
	Spread by boating likely	X		Heavily boated lake	X			
	Spread by other human activities likely		X	Low probability			X	
Potential success of rapid response	Eradication is possible		X	Not yet successful anywhere once established			X	
	Confinement is possible		X	Cannot prevent water movement			X	

Presence of more vegetation can enhance fish habitat in systems where plants are scarce, but when dense submergent plants cover a substantial portion of a waterbody (usually estimated at about 20%), predatory gamefish find it difficult to forage. With greater coverage (often estimated at 40%), prey panfish populations are protected from predation and often become too large for available food resources. Panfish growth slows and stunting of fish occurs. With 43% of the reservoir subject to dense hydrilla growths now, hydrilla cannot be considered a benefit to the fishery.

Invasion of the southwestern arm of the reservoir seems unavoidable, and the same impairment of boating and fishing currently experienced in the northwest arm can be expected in the southwestern arm. Loss of native plant diversity would occur, with most of the native species now in the reservoir having their greatest abundance in the southwestern arm. Reduced foraging areas could impact non-aquatic but water-dependent species, such as birds that eat fish. Overall aesthetics of the reservoir would be further compromised.

The impact on boating will be significant until the boats reach water about 10 feet deep, representing about 57% of the lake now but potentially only 47% when hydrilla reaches its projected maximum coverage. Since shallow water is most impacted, and boats are moored or docked near shoreline, the negative effect on boaters is immediate upon attempting to enter the reservoir in any infested area. Few segments of shoreline are steep enough to get deep enough fast enough to eliminate aggravation for boaters. The extensive coverage by hydrilla in the upstream portion of the northwest arm of the reservoir eliminates use of that area by boats, crowding boaters into a smaller area. The reservoir may not look different when viewed from an oblique angle from a backyard or deck, but from a boat looking down it will be less appealing.

Spread of hydrilla within the reservoir by boats is possible, and spread to other waterbodies from Swift Creek Reservoir is also a threat. A program of boat cleaning could minimize boat-induced spread, but any movement of hydrilla downstream with water flow is not realistically preventable. At the very least, access points should be posted with signs that include language such as "*Help protect our lake! Invasive species of plants and animals can alter the lake in ways that could impair enjoyment of it and its use as a water supply. Before launching or leaving this access point, please remove all plants and animals from the boat and dispose of them in a manner that will prevent their spread. Drain all water from the boat and motor away from the access, so that this water goes into the ground, not the lake or any watercourse. When moving a boat between lakes, wash the boat with a power sprayer and/or keep it dry for at least 5 days in between uses*." A contact name and number should also be given for those with questions. Provision of boat washing stations is desirable but expensive, and will have little impact on the current infestation in Swift Creek Reservoir.

5.0 Alternatives for Macrophyte Management

5.1 Overview

There are many possible approaches to plant control in general, but only a portion of these apply to hydrilla, and actual applicability is dependent on specific conditions in the target waterbody. Table 2 provides a listing of common plant management techniques, with mode of action, major advantages and drawbacks, and a brief assessment of applicability to the hydrilla situation in Swift Creek Reservoir. Inapplicability results from:

1. The method is not effective for hydrilla, although it may be effective against other species.
2. The method is not allowed or advisable in a potable water supply as a consequence of impact on drinking water quality.
3. The technique has impacts on other uses of the reservoir that make it unattractive.
4. The scale of the problem is not a good match for the typical level of application of the control method.

All techniques have benefits and disadvantages, but many are simply not applicable or not appropriate, as outlined in Table 2. Cost is not used as a criterion here, but will certainly affect the choice of potentially applicable control methods. Methods with enough potential for managing hydrilla in Swift Creek Reservoir to warrant more detailed review include:

1. Benthic barriers on a localized scale, to facilitate access by boats to deeper water or create boating lanes in shallow areas infested with dense hydrilla growths.
2. Dredging, either peripherally under dry conditions created by a drawdown or wherever desired hydraulically with the reservoir at full level.
3. Mechanical harvesting to maintain boating access, since hydrilla has already occupied most of the possible area of the reservoir it can infest.
4. Drawdown, either to facilitate peripheral excavation of sediments and plants, or to directly kill plants.
5. Application of fluridone, an herbicide that is effective against hydrilla and is used in drinking water reservoirs.
6. Stocking of grass carp, a fish that eats plants including hydrilla, and could consume enough over several years to limit hydrilla densities to an acceptable level.

Using the information provided in the Generic Environmental Impact Report for lake management methods (Mattson et al. 2004), its companion guide (Wagner 2004), and the most recent edition of Restoration and Management of Lakes and Reservoirs (Cooke et al. 2005), along with personal experience, the following review of applicable techniques for control of hydrilla in Swift Creek Reservoir is provided.

Table 2. Options for control of macrophytes. (Adapted from Wagner 2001).

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
Physical Controls				
1) Benthic barriers	♦ Mat of variable composition laid on bottom of target area, preventing growth ♦ Can cover area for as little as several months or permanently ♦ Maintenance improves effectiveness	♦ Highly flexible control ♦ Reduces turbidity from soft bottoms ♦ Can cover undesirable substrate ♦ Can improve fish habitat by creating edge effects	♦ May cause anoxia at sediment-water interface ♦ May limit benthic invertebrates ♦ Non-selective interference with plants in target area ♦ May inhibit spawning/feeding by some fish species	♦ Highly applicable on a localized basis; could allow for boat access through dense vegetation with limited maintenance, but rarely used on a large scale, due to cost and logistic considerations.
1.a) Porous or loose-weave synthetic materials	♦ Laid on bottom and usually anchored by weights or stakes ♦ Removed and cleaned or flipped and repositioned at least once per year for maximum effect	♦ Allows some escape of gases which may build up underneath ♦ Panels may be flipped in place or removed for relatively easy cleaning or repositioning	♦ Allows some growth through pores ♦ Gas may still build up underneath in some cases, lifting barrier from bottom	♦ Appropriate, but will allow some growth through pores; plant fragments may land on screen and root down through it.
1.b) Non-porous or sheet synthetic materials	♦ Laid on bottom and anchored by many stakes, anchors or weights, or by layer of sand ♦ Not typically removed, but may be swept or "blown" clean periodically	♦ Prevents all plant growth until buried by sediment ♦ Minimizes interaction of sediment and water column	♦ Gas build up may cause barrier to float upwards ♦ Strong anchoring makes removal difficult and can hinder maintenance	♦ Appropriate, but may need slits to vent trapped gases; probably more suitable to boating access in this situation.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
1.c) Sediments of a desirable composition	♦ Sediments may be added on top of existing sediments or plants. ♦ Use of sand or clay can limit plant growths and alter sediment-water interactions. ♦ Sediments can be applied from the surface or suction dredged from below muck layer (reverse layering technique)	♦ Plant biomass and propagules can be buried ♦ Sediment can be made less hospitable ♦ Nutrient release from sediments may be reduced ♦ Surface sediment can be made more appealing to humans ♦ Reverse layering requires no addition or removal of sediment	♦ Lake depth may decline ♦ Sediments may mix with underlayment ♦ Permitting for added sediment difficult ♦ Addition of sediment may cause initial turbidity ♦ New sediment may contain nutrients or other contaminants ♦ Generally too expensive for large scale application	♦ Would reduce reservoir volume and hydrilla is likely to regrow unless gravel is used.
2) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Plants and seed beds are removed and re-growth can be limited by light and/or substrate limitation	♦ Plant removal with some flexibility ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with uses during dredging ♦ Usually very expensive	♦ Highly applicable; removes plants, related propagules, deepens reservoir, removes accumulated contaminants; cost is the main limiting factor for this approach

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
2.a) “Dry” excavation	♦ Lake drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Eliminates most aquatic biota unless a portion left undrained ♦ Eliminates lake use during dredging	♦ Possible to work under “dry” conditions with a drawdown, facilitates potentially very thorough removal in accessible areas.
2.b) “Wet” excavation	♦ Lake level may be lowered, but sediments not substantially dewatered ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Tends to require less preparation and be less costly than dry dredging ♦ May allow use of easily acquired equipment ♦ May preserve most aquatic biota	♦ Usually creates extreme turbidity ♦ Sediment deposition in surrounding area ♦ Normally requires containment area to dry sediments prior to hauling ♦ Severe disruption of ecological function ♦ Lake uses impaired during dredging	♦ Generation of turbidity and spread of hydrilla likely, generally not a desirable approach in an active supply reservoir.
2.c) Hydraulic (or pneumatic) removal	♦ Lake level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and limits impact on biota ♦ Can allow some lake uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle extremely coarse or debris-laden materials ♦ Requires advanced and more expensive containment area ♦ Requires overflow discharge from containment area	♦ Applicable where water level control is inadequate to allow work under dry conditions. Flexible application over space and time. Primary consideration is need for dewatering area and quality of return water.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
3) Dyes and surface covers	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting plant growth ♦ Dyes remain in solution until washed out of system. ♦ Opaque sheet material applied to water surface	♦ Light limit on plant growth without high turbidity or great depth ♦ May achieve some control of algae as well ♦ May achieve some selectivity for species tolerant of low light	♦ May not control peripheral or shallow water rooted plants ♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water ♦ Covers inhibit gas exchange with atmosphere	♦ Would impede recreation and alter aesthetics; possible negative consequences for water supply, either perceived (dyes) or actual (boating interference or oxygen issues under covers).
4) Mechanical removal (“harvesting”)	♦ Plants reduced by mechanical means, possibly with disturbance of soils ♦ Collected plants may be placed on shore for composting or other disposal ♦ Wide range of techniques employed, from manual to highly mechanized ♦ Application once or twice per year usually needed	♦ Highly flexible control ♦ May remove other debris ♦ Can balance habitat and recreational needs	♦ Possible impacts on aquatic fauna ♦ Non-selective removal of plants in treated area ♦ Possible spread of undesirable species by fragmentation ♦ Possible generation of turbidity	♦ Where problem plants occupy maximum area possible, this is akin to mowing the lawn and can be effective for maintaining uses. Primary issue will be cost over long term, with ongoing application needed.
4.a) Hand pulling	♦ Plants uprooted by hand (“weeding”) and preferably removed	♦ Highly selective technique	♦ Labor intensive ♦ Difficult to perform in dense stands	♦ Infestation is beyond point of applicability for hand removal other than at most localized level.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
4.b) Cutting (without collection)	♦ Plants cut in place above roots without being harvested	♦ Generally efficient and less expensive than complete harvesting	♦ Leaves root systems and part of plant for re-growth ♦ Leaves cut vegetation to decay or to re-root ♦ Not selective within applied area	♦ Ability of hydrilla fragments to re-root negates effectiveness of this option; will spread plant.
4.c) Harvesting (with collection)	♦ Plants cut at depth of 2-10 feet and collected for removal from lake	♦ Allows plant removal on greater scale	♦ Limited depth of operation ♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ More expensive than cutting	♦ Appropriate on a maintenance basis, but not completely efficient at collection. Applied where target plants are already occupying most of possible area.
4.d) Rototilling	♦ Plants, root systems, and surrounding sediment disturbed with mechanical blades	♦ Can thoroughly disrupt entire plant	♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ Creates substantial turbidity ♦ More expensive than harvesting	♦ Creates high turbidity, unlikely to control hydrilla growths for more than a year.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
4.e) Hydroraking	♦ Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, part of material usually collected and removed from lake	♦ Can thoroughly disrupt entire plant ♦ Also allows removal of stumps or other obstructions	♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ Creates substantial turbidity ♦ More expensive than harvesting	♦ Largely inapplicable. Less effective than harvesting with collection, similar impacts to cutting without collecting, but with high turbidity generation.
5) Water level control	♦ Lowering or raising the water level to lower suitability for aquatic plants ♦ Disrupts plant life cycle by drying/ freezing, or light limitation	♦ Requires only outlet control to affect large area ♦ Provides widespread control in increments of water depth ♦ Complements dredging and flushing	♦ Potential issues with water supply ♦ Potential issues with flooding ♦ Potential impacts to non-target flora and fauna	♦ Potential issues with property damage limit increases in water level. Drawdown could kill plants but not tubers.
5.a) Drawdown	♦ Lowering of water over winter period allows desiccation, freezing, and physical disruption of plants, roots and seed beds ♦ Timing and duration of exposure and degree of dewatering are critical aspects ♦ Variable species tolerance to drawdown	♦ Control with some flexibility ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ Impacts vegetative propagation species with limited impact to seed producing populations	♦ Possible impacts on emergent wetlands ♦ Possible effects on overwintering reptiles and amphibians ♦ Reduction in potential supply ♦ Alteration of downstream flows ♦ Possible overwinter water level variation ♦ May result in greater nutrient availability for algae	♦ Long term alteration of sediment features through drawdown will limit plant growths, but could take several decades. Direct impacts on plants possible, but germination of new plants from tubers and surviving root systems is expected. Inexpensive option, but potential impact on water supply must be evaluated.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
5.b) Flooding	♦ Higher water level in the spring can inhibit seed germination and plant growth ♦ Higher flows which are normally associated with elevated water levels can flush seed and plant fragments from system	♦ Where water is available, this can be an inexpensive technique ♦ Plant growth need not be eliminated, merely retarded or delayed ♦ Timing of water level control can selectively favor certain desirable species	♦ Water for raising the level may not be available ♦ Potential peripheral flooding ♦ Possible downstream impacts ♦ Many species may not be affected, and some may be benefitted ♦ Algal nuisances may increase where nutrients are available	♦ Issues with peripheral private property limit water level rise; would not eliminate problems with peripheral growths, which are the primary problem in this case.
Chemical controls				
6) Herbicides	♦ Liquid or pelletized herbicides applied to target area or to plants directly ♦ Contact or systemic poisons kill plants or limit growth ♦ Typically requires application every 1-5 yrs	♦ Wide range of control is possible ♦ May be able to selectively eliminate species ♦ May achieve some algae control as well	♦ Possible toxicity to non-target species ♦ Possible downstream impacts ♦ Restrictions of water use for varying time after treatment ♦ Increased oxygen demand from decaying vegetation ♦ Possible recycling of nutrients to allow other growths	♦ Only a few herbicides approved for use in potable supplies, but applicable to gain initial control.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
6.a) Forms of copper	♦ Contact herbicide ♦ Cellular toxicant, suspected membrane transport disruption ♦ Applied as wide variety of liquid or granular formulations	♦ Moderately effective control of some submersed plant species ♦ More often an algal control agent	♦ Toxic to aquatic fauna as a function of concentration, formulation, and water chemistry ♦ Ineffective at colder temperatures ♦ Copper ion persistent; accumulates in sediments	♦ Some impact on hydrilla, but used more often to kill associated algae and make plants more susceptible to other herbicides.
6.b) Forms of endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid)	♦ Contact herbicide with limited translocation potential ♦ Membrane-active chemical which inhibits protein synthesis ♦ Causes structural deterioration ♦ Applied as liquid or granules	♦ Moderate control of some emersed plant species, moderately to highly effective control of floating and submersed species ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to aquatic fauna (varying degrees by formulation) ♦ Time delays on use for water supply, agriculture and recreation ♦ Safety hazards for applicators	♦ Inappropriate for use in potable supply.
6.c) Forms of diquat (6,7-dihydropyrido [1,2-2',1'-c] pyrazinediium dibromide)	♦ Contact herbicide ♦ Absorbed by foliage but not roots ♦ Strong oxidant; disrupts most cellular functions ♦ Applied as a liquid, sometimes in conjunction with copper	♦ Moderate control of some emersed plant species, moderately to highly effective control of floating or submersed species ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to zooplankton at recommended dosage ♦ Inactivated by suspended particles; ineffective in muddy waters ♦ Time delays on use for water supply, agriculture and recreation	♦ Can be used in potable supplies with limits, but kills only the contacted portion of plants; regrowth will occur within a year in most cases.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
6.d) Forms of glyphosate (N-[phosphonomethyl glycine)	♦ Contact herbicide ♦ Absorbed through foliage, disrupts enzyme formation and function in uncertain manner ♦ Applied as liquid spray	♦ Moderately to highly effective control of emersed and floating plant species ♦ Can be used selectively, based on application to individual plants ♦ Rapid action ♦ Low toxicity to aquatic fauna at recommended dosages ♦ No time delays for use of treated water	♦ Non-selective in treated area ♦ Inactivation by suspended particles; ineffective in muddy waters ♦ Not for use within 0.5 miles of potable water intakes ♦ Highly corrosive; storage precautions necessary	♦ Not effective against hydrilla.
6.e) Forms of 2,4-D (2,4-dichlorophenoxyl acetic acid)	♦ Systemic herbicide ♦ Readily absorbed and translocated throughout plant ♦ Inhibits cell division in new tissue, stimulates growth in older tissue, resulting in gradual cell disruption ♦ Applied as liquid or granules, frequently as part of more complex formulations, preferably during early growth phase of plants	♦ Moderately to highly effective control of a variety of emersed, floating and submersed plants ♦ Can achieve some selectivity through application timing and concentration ♦ Fairly fast action	♦ Variable toxicity to aquatic fauna, depending upon formulation and ambient water chemistry ♦ Time delays for use of treated water for agriculture and recreation ♦ Not for use in water supplies	♦ Inappropriate for use in potable supply.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
6.f) Forms of fluridone (1-methyl-3-phenyl-5-[-3-{trifluoromethyl} phenyl]-4[IH]-pyridinone)	♦ Systemic herbicide ♦ Inhibits carotenoid pigment synthesis and impacts photosynthesis ♦ Best applied as liquid or granules during early growth phase of plants	♦ Can be used selectively, based on concentration ♦ Gradual deterioration of affected plants limits impact on oxygen level (BOD) ♦ Effective against several difficult-to-control species ♦ Low toxicity to fauna	♦ Impacts on non-target plant species possible at higher doses ♦ Extremely soluble and mixable; difficult to perform partial lake treatments ♦ Requires extended contact time	♦ Most effective herbicide for hydrilla, used at <10 ppb in most cases, Used in drinking water supplies at least ¼ mile from intakes. Will not kill tubers, so repeated treatments necessary.
6.g Amine salt of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid)	♦ Systemic herbicide ♦ Readily absorbed by foliage, translocated throughout plant ♦ Disrupts enzyme systems specific to plants ♦ Applied as liquid spray or subsurface injected liquid	♦ Effectively controls many floating and submersed plant species ♦ Selectively effective against dicot plant species, including many nuisance species ♦ Effective against several difficult-to-control species ♦ Low toxicity to fauna ♦ Fast action	♦ Impacts on non-target plant species possible at higher doses ♦ Current time delay of 30 days on consumption of fish from treated areas ♦ Necessary restrictions on use of treated water for supply or recreation not yet certain	♦ Not effective against hydrilla.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY
Biological Controls				
7) Biological introductions	♦ Fish, insects or pathogens which feed on or parasitize plants are added to system to affect control ♦ Grass carp most commonly used, but the larvae of several insects have been used and viruses are being tested	♦ Provides potentially continuing control with one treatment ♦ Harnesses biological interactions to produce desired conditions ♦ May produce potentially useful fish biomass as an end product	♦ Typically involves introduction of non-native species ♦ Effects may not be controllable ♦ Plant selectivity may not match desired target species ♦ May adversely affect indigenous species	♦ Exercise caution; unintended consequences are very common with introductions of species new to aquatic systems. Potential control at acceptable level is possible for hydrilla, however.
7.a) Herbivorous fish	♦ Sterile juveniles stocked at density which allows control over multiple years ♦ Growth of individuals offsets losses or may increase herbivorous pressure	♦ May greatly reduce plant biomass in single season ♦ May provide multiple years of control from single stocking ♦ Sterility intended to prevent population perpetuation and allow later adjustments	♦ May eliminate all plant biomass, or impact non-target species ♦ Funnels energy into algae ♦ Alters habitat ♦ May escape upstream or downstream ♦ Population control issues	♦ Grass carp used in other Virginia reservoirs, mixed results over about 20 years of application in the USA, grass carp will consume plant biomass and grow, but will release nutrients that may grow more algae.
7.b) Herbivorous insects	♦ Larvae or adults stocked at density intended to allow control with limited growth ♦ Intended to selectively control target species ♦ Milfoil weevil is best known, but still experimental	♦ Involves species native to region, or even targeted lake ♦ Expected to have no negative effect on non-target species ♦ May facilitate longer term control with limited management	♦ Incomplete control likely; oscillating cycle of control and re-growth expected ♦ Predation by fish may complicate control ♦ Other lake management actions may interfere	♦ None known to be effective against hydrilla.

7.c) Fungal/bacterial/ viral pathogens	♦ Inoculum used to seed lake or target plant patch ♦ Growth of pathogen population expected to achieve control over target species	♦ May be highly species specific ♦ May provide substantial control after minimal inoculation effort	♦ Effectiveness and longevity of control not well known ♦ Infection ecology suggests incomplete control likely	♦ None known to be effective against hydrilla.
7.d) Selective plantings	♦ Establishment of plant assemblage resistant to undesirable species ♦ Plants introduced as seeds, cuttings or whole plants	♦ Can restore native assemblage ♦ Can encourage assemblage most suitable to lake uses ♦ Supplements targeted species removal effort	♦ Largely experimental ♦ May not prevent nuisance species from returning ♦ Introduced species may become nuisances	♦ A healthy native assemblage is more resistant to hydrilla invasion, but hydrilla is a superior competitor for space and light in most cases.

5.2 Benthic Barriers

5.2.1 How This Method Works

The use of benthic barriers, or bottom covers, is predicated upon the principles that rooted plants require light and cannot grow through physical barriers. Applications of clay, silt, sand, and gravel have been used for many years, although plants often root in these covers eventually, and current environmental regulations make it difficult to gain approval for such deposition of fill. Artificial sediment covering materials, including polyethylene, polypropylene, fiberglass, and nylon, have been developed over the last three decades. A variety of solid and porous forms have been used. Manufactured benthic barriers are negatively buoyant materials, usually in sheet form, which can be applied on top of plants to limit light, physically disrupt growth, and allow unfavorable chemical reactions to interfere with further development of plants. Various plastics and burlap have also been used, but are not nearly as durable or effective in most cases.

Benthic barriers can be effectively used in small areas such as around docks or to create access lanes through plant growth. Large areas are not often treated, however, because the cost of materials (about $20,000-40,000/acre), application ($5,000/acre) and maintenance (annual repeat of application) is high. Benthic barriers will eliminate or strongly reduce all submergent plant growth where applied. Benthic barrier problems of prime concern include long-term integrity of the barrier, billowing caused by trapped gases, accumulation of sediment on top of barriers, and growth of plants on porous barriers. Successful use is related to selection of materials and the quality of the installation. As a result of field experience with benthic barriers, several guidelines can be offered:

- Porous barriers will be subject to less billowing, but will allow settling plant fragments to root and grow; annual maintenance is therefore essential, usually by divers or snorkelers, making these inappropriate for Swift Creek Reservoir.
- Solid barriers will generally prevent rooting in the absence of sediment accumulations, but will billow after enough gases accumulate; venting and strong anchoring are essential in most cases, but these could be used in Swift Creek Reservoir.
- Plants under the barrier will usually die completely after one to two months, with solid barriers more effective than porous ones in killing the whole plant; barriers of sufficient tensile strength can then be moved to a new location, although continued presence of solid barriers restricts recolonization, and frequent human contact with Swift Creek Reservoir is discouraged.

Proper application requires that the screens be placed on the sediment surface and staked or securely anchored. This may be difficult to accomplish over dense plant growth, but with enough weight (e.g., patio blocks, sheathed rebar), it can be accomplished. Scuba divers normally apply the covers in deeper water (greater than 8 feet), which greatly increases labor costs, but application in Swift Creek Reservoir is likely to be restricted to areas less than 8 feet deep. Bottom barriers will accumulate sediment deposits in most cases, which allow plant fragments to root. Barriers must then be cleaned, necessitating either removal or laborious in-place maintenance. Despite application and maintenance issues, a benthic barrier can be a very effective tool. Benthic barriers are capable of providing control of rooted plants on at least a localized basis, and have such desirable side benefits as creating more edge habitat within dense plant assemblages and minimizing turbidity generation from fine bottom sediments.

There are many ways to install barriers, ranging from spreading them out with the lake drawn down to underwater positioning by divers. In water less than about 10 feet deep, snorkeling may be sufficient to get the barrier properly positioned. One aid to application involves rolling the barrier onto PVC pipe with a slightly longer wooden or metal pole inside the PVC pipe, allowing the barrier to be rolled out like paper towels. Anchoring systems vary with barrier type, but most forms do require staking or weighting. Sleeves can be sewn into sheet materials to allow rebar to be inserted, pieces of chain can be attached to edges, or patio blocks can be dropped onto the barrier to hold it in place. Burial under sandy sediments has been tried, but will allow more rapid plant recolonization. Where removal at a later date is desired, the weighting system should be simple and reversible (patio block weights are very convenient in this regard).

5.2.2 Information for Proper Application

- Mapping of area to be covered by barrier, with information on plant types and density
- Knowledge of sediment features, along with any obstructions or other interference factors
- Inventory of biological features of the target area, especially the presence of any protected species
- Plan for installation and maintenance

5.2.3 Factors Favoring the Use of this Technique

- The target area has dense plant growths of undesirable species
- The target area is small (<1 acre) and relatively free of obstructions (stumps, logs, boulders, pilings and moorings)
- The target area represents only a small portion of the whole lake (<10%)
- Long-term control is sought over a small area with recognition of necessary maintenance needs
- Inexpensive labor is available
- No significant shellfish resources are present in the target area
- A favorable plant assemblage is expected to develop (or can be encouraged by planting) after barrier removal

5.2.4 Performance Guidelines for Swift Creek Reservoir

- Generate a lakewide plan for barrier use; do not simply allow shoreline residents to address their own areas without consideration of the overall impact or possible efficiencies of group action.
- Select a benthic barrier with properties consistent with project goals and site features; a solid barrier such as hypalon (landfill liner) would be appropriate.
- Avoid installation over >10% of lake littoral zone
- Lay out and anchor barrier in a manner that maximizes stability in response to wave action or other influences
- Develop a maintenance program that monitors and maximizes barrier effectiveness
- Monitor the plant community before and after barrier application
- Monitor water quality near the barrier and in the lake in general if the installation is large (>1 acre)

5.3 Mechanical Harvesting

5.3.1 How This Method Works

Mechanical harvesting is most often associated with large machines on pontoons that cut and collect vegetation, but encompasses a range of techniques from simply cutting the vegetation in place to cutting, collecting, and grinding the plants, to collection and disposal outside the lake. From the perspective of the needs and uses of Swift Creek Reservoir, only mechanical harvesting with removal of harvested plants is appropriate and will be considered here.

Advanced technology cutting techniques involve the use of mechanized barges with which plants are collected for out-of-lake disposal. Larger, commercial machines have numerous blades, a conveyor system, and a substantial storage area for cut plants. Offloading accessories are available, allowing easy transfer of weeds from the harvester to trucks that haul the weeds to a composting area. Choice of equipment is really a question of scale, with larger harvesting operations usually employing commercially manufactured machines built to specifications suited to the job. Some lake associations choose to purchase and operate harvesters, while others prefer to contract harvesting services to a firm that specializes in lake management efforts.

Cutting rates for commercial harvesters tend to range from about 0.2 to 0.6 acres per hour, depending on machine size and operator ability, but the range of possible rates is larger and is often dependent upon distance to the offloading location when out-of-lake disposal is planned. Even at the highest conceivable rate, harvesting is a slow process that may leave some lake users dissatisfied with progress in controlling aquatic plants. Weed disposal is not usually a problem, in part because lakeshore residents and farmers often will use the weeds as mulch and fertilizer. Also, since aquatic plants are more than 90 percent water, their dry bulk is comparatively small. Key issues in choosing a harvester include depth of operation, volume and weight of plants that can be stored, reliability and ease of maintenance, along with a host of details regarding the hydraulic system and other mechanical design features.

Regrowth of plants is expected, and in some species that regrowth is so rapid that it negates the benefits of the cutting in only a few weeks. If the plant can be cut close enough to the bottom, or repeatedly, it will sometimes die, but this is more the exception than the rule. Over several years of harvesting, the plant community will sometimes shift toward lower growing, more desirable species, but there is no guarantee that such a shift will occur. It is generally assumed that harvesting will be a maintenance technique, applied on an ongoing basis as needed to keep conditions acceptable for the designated uses.

Collection systems are not 100% effective; some plant fragments will remain in the water, and those plants that can form roots from fragments will spread as a result. Large scale harvesting is therefore only advisable if all or at least most of the area that might be colonized has already been infested. This is the case for hydrilla in Swift Creek Reservoir.

5.3.2 Information for Proper Application

- ♦ General plant mapping and knowledge of any sensitive areas, especially where protected species are involved
- ♦ For large or repeated efforts, more detailed mapping with estimates of cover or biomass that aid planning
- ♦ Fragment control plan, where species that expand by this process are not yet dominant or where downstream movement must be prevented
- ♦ Harvesting plan to include areas to be harvested, timing and pattern of harvest, and means to dispose of the plant material
- ♦ Information on underwater obstructions, shallow areas, and other possible interference factors
- ♦ Monitoring plan for assessing results, including impact on plant types and abundance, regrowth rates, achieved cutting rate, and any impacts to non-target organisms of concern

5.3.3 Factors Favoring the Use of this Technique

- ♦ The plant community is dominated by undesirable species
- ♦ Overall density of macrophytes is excessive throughout the littoral zone
- ♦ Surficial and underwater obstructions in targeted areas are minimal
- ♦ Suspended sediments resettle quickly and leave minimal residual turbidity
- ♦ Convenient access for equipment and trucks and a nearby location for plant disposal are available

5.3.4 Performance Guidelines for Swift Creek Reservoir

- Map the distribution of the target species and non-target species in the lake
- Develop a harvesting plan that divides the lake into zones and addresses which zones will be harvested in what order, designated offloading sites, and any protected (no harvest) areas
- Select equipment consistent with goals; cutting depth and hopper capacity are important features, and auxiliary barges and offloading equipment may improve efficiency
- Inspect and clean all equipment before entering or leaving the reservoir
- Avoid areas of known sensitive habitat during active use by key species
- Harvest as close to the bottom as equipment allows for maximum effect; actually disturbing the root systems in soft sediment may prolong control, but may also produce excessive turbidity
- Monitor pre- and post-harvest density of target plants and the plant community in general
- Monitor collection of non-target fauna (e.g., fish, turtles) and avoid excessive collection
- Develop a harvester maintenance plan; routine repairs are essential to keeping a harvesting program on schedule

5.4 Drawdown

5.4.1 How This Method Works

Drawdown is a process whereby the water level is lowered by gravity, pumping or siphoning and held at that reduced level for some period of time, typically several months and usually over the winter. Drawdown can provide control of plant species that overwinter in a vegetative state, and oxidation of sediments may result in lower nutrient levels with adequate flushing. Drawdowns also provide flood control and allow access for nearshore clean ups and repairs to structures. The ability to control the water level in a lake is affected by area precipitation pattern, system hydrology, lake morphometry, and the outlet structure. The base elevation of the outlet or associated subsurface pipe(s) will usually set the maximum drawdown level, while the capacity of the outlet to pass water and the pattern of water inflow to the lake will determine if that base elevation can be achieved and maintained. In some cases, sedimentation of an outlet channel or other obstructions may control the maximum drawdown level.

Several factors affect the success of drawdown with respect to plant control. While drying of plants during drawdowns may provide some control, the additional impact of freezing is substantial, making drawdown a more effective strategy during late fall and winter in cold climates. However, a mild winter may not provide the necessary level of drying and freezing. The presence of high levels of groundwater seepage into the lake may mitigate or negate destructive effects on target submergent species by keeping the area moist and unfrozen. The presence of extensive seed beds, tubers or root crowns may result in rapid re-establishment of previously occurring plant species. Recolonization from nearby areas may be rapid, and the response of macrophyte species to drawdown is quite variable.

Aside from direct impact on target plants, drawdown can also indirectly and gradually affect the plant community by changing the substrate composition in the drawdown zone. If there is sufficient slope, finer sediments will be transported to deeper waters, leaving behind a coarser substrate. If there is a thick muck layer present in the drawdown zone, there is probably not adequate slope to allow its movement. However, where light sediment has accumulated over sand, gravel or rock, repetitive drawdowns can restore the coarse substrate and limit plant growths.

The actual conduct of a drawdown involves facilitating more outflow than inflow for several weeks or months. After the target water level is reached, outflow is roughly matched to inflow to maintain the drawdown for the desired period. At a time picked to allow refill before any undesirable spring impacts can occur, outflow is reduced (although it should not be eliminated) and “excess” inflow causes the water level to rise.

Despite the apparent simplicity of the concept of drawdown, proper conduct of a drawdown to maximize effectiveness and minimize adverse side effects necessitates that many considerations be addressed. Expected response of target species is of particular importance when plant control is the major goal. In Swift Creek Reservoir, actual hydrilla plants would be adversely affected by drawdown, but regrowth from tubers and possibly seeds would be expected to offset gains for multiple years.

5.4.2 Information for Proper Application

- Detailed hydrology and lake morphometry to allow estimates of drawdown and refill times under the range of potential conditions
- Knowledge of outlet features essential to releasing and holding water
- Maps of aquatic macrophytes and expected area of exposure
- Evaluation of sediment types and slopes in expected drawdown zone
- Biological surveys of populations perceived to be at risk from drawdown
- Assessment of downstream channel configuration and resources, to facilitate planning to minimize adverse impacts
- Local well depths or water supply intake elevations
- A carefully crafted monitoring program to track water levels and outflow, and to assess potential impacts, positive and negative

5.4.3 Factors Favoring the Use of this Technique

- The lake periphery is dominated by undesirable species that are susceptible to drying and freezing

- Drawdown can be achieved by gravity outflow via an existing outlet structure, or such a structure can be established for a reasonable cost
- Drawdown can reach a depth that impacts enough of the targeted plants to make a difference for recreational interests and habitat enhancement
- Areas to be exposed have sediments and slopes that promote dewatering
- Drawdown and refill can be accomplished within a few weeks under typical flow conditions and without causing downstream flows outside the natural range
- Drawdown can be timed to avoid key migration and spawning periods for non-target organisms
- Populations of mollusks or other nearshore-dwelling organisms of limited mobility are not significant
- Direct water supply functions will not be impacted and nearby wells are deep
- Flood storage capacity generated by drawdown prevents downstream flood impacts
- The downstream channel and associated resources will not be impacted by fluctuating flows expected during drawdown and refill periods

5.4.4 Performance Guidelines for Swift Creek Reservoir

- Evaluate potential risks to non-target flora and fauna
- Target drawdown at 8 feet if a hydrologic analysis will support this level with adequate spring refill
- Commence drawdown in mid-October
- Achieve the target drawdown depth by late November; target a drawdown rate of <3 inches/day
- Achieve full lake status by the beginning of April
- Once the target water level is achieved, match outflow to inflow to the greatest extent possible, maintaining a stable water level
- Keep outflow during refill above a discharge equivalent to at least 0.2 cfs per square mile of watershed
- Conduct a monitoring program that includes water level, flow, water clarity, winter oxygen, the plant community, and representative sensitive faunal populations

Note that drawdown might be applied to Swift Creek Reservoir to facilitate access for dredging, rather than for direct plant control, in which case the above performance standards still apply, but additional standards related to dredging will be applicable.

5.5 Dredging

5.5.1 How This Method Works

Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic dredging are possible approaches to dredging, and planning and impact considerations vary substantially by approach. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of invasive growths of macrophytes. Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. Dredging also removes the accumulated seed bed established by many vascular plants. Dry, wet and hydraulic methods are illustrated in Figure 5.

Dry dredging involves partially or completely draining the reservoir and removing the exposed bottom sediments with a bulldozer or other conventional excavation equipment. Projects involving silts, sands, gravel and larger obstructions where water level can be controlled favor conventional, dry methodology. Although exposed areas do not always dry to the point where equipment can be used without some form of support (e.g., railroad tie mats or gravel placed to form a road), excavating under "dry" conditions allows very thorough sediment removal and a complete restructuring of the pond bottom. The term "dry" may be a misnomer in many cases, as organic sediments will not dewater sufficiently to be moved like upland soils. Dry dredging may resemble a large-scale excavation of pudding, and the more the material is handled, the more liquid it becomes.

Control of inflow to the lake is critical during dry excavation. For dry excavation, water can often be routed through the lake in a sequestered channel or pipe, limiting interaction with disturbed sediments. Water added from upstream or directly from precipitation will result in solids content rarely in excess of 50% and often as low as 30%. Consequently, some form of containment area is needed before material can be used productively in upland projects. Where there is an old gravel pit or similar area to be filled, one-step disposal is facilitated, but most projects involve temporary and permanent disposal steps.

Hydraulic dredging usually involves a suction type of dredge that has a cutter head. Agitation combined with suction removes the sediments as a slurry which contains approximately 15-20% solids by volume, although this may increase to as high as 30 to 40% in some cases or be as low as 5% with especially watery sediments in difficult areas. This slurry is typically pumped to a containment area in an upland setting where the excess water can be separated from the solids by settling (with or without augmentation). The supernatant water can be released back to the reservoir or some other waterway. The containment area for a hydraulic dredging project is usually a shallow diked area that is used as a settling basin. The clarified water may be treated with flocculation and coagulation techniques to further reduce the suspended solids in the return water.

Hydraulic dredging is normally favored for removal of large amounts of highly organic sediments with few rocks, stumps or other obstructions and where water level control is limited. This type of project does require a containment area to be available where removed sediments are separated from water, and may involve secondary removal of the dried sediment from the containment area for ultimate disposal elsewhere. Usually the containment area is not far from the lake, but a slurry can be pumped multiple miles along a suitable route with booster pumps.

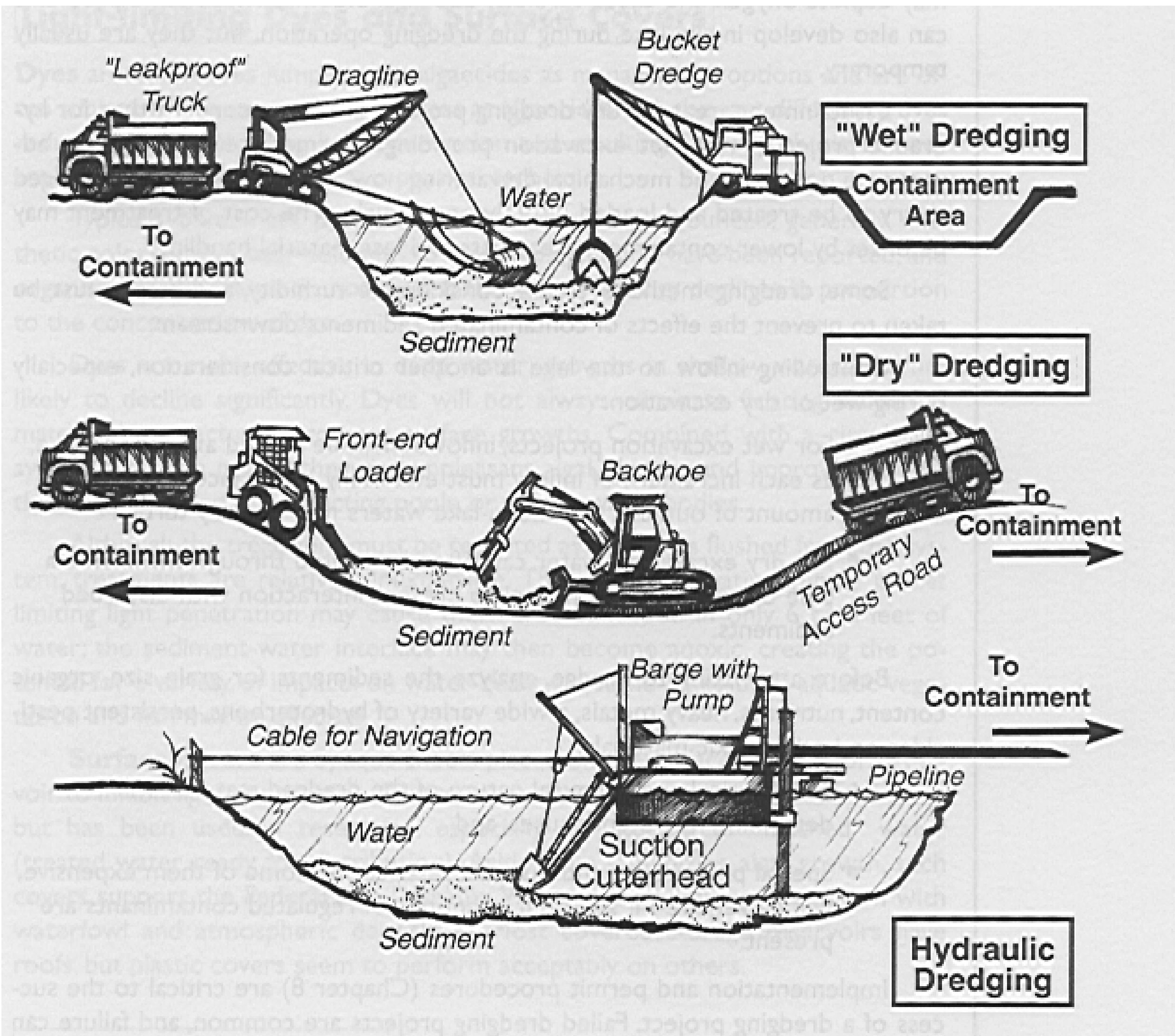

Figure 5. Wet, Dry and Hydraulic Dredging Approaches (from Wagner, 2001).

Innovations in polymers and belt presses for sediment dewatering have reached the point where hydraulically dredged slurry can be treated as it leaves the lake to the extent necessary to load it directly onto trucks for transport to more remote sites. Solids content of the resultant material is still too low for many uses without further drying or mixing with sand, but the need for a large containment area can be avoided with this technology. The cost of coagulation and mechanical dewatering may be at least partially offset by savings in containment area construction and ultimate material disposal. Likewise, pumping the slurry into geo-tubes (engineered filter bags) can also enhance dewatering in a limited space.

Wet dredging involves draglines or bucket dredges that remove sediment without complete drawdown, and can be very messy operations. Even with so called "environmental" bucket dredges, turbidity generation can be high, and this approach was not considered appropriate for Swift Creek Reservoir. Any dredging in Swift Creek Reservoir would most likely be conducted as conventional excavation in peripheral areas during a drawdown or by hydraulic means anywhere desired with the reservoir at full level.

A properly conducted dredging program removes accumulated sediment and effectively sets the reservoir back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all "soft" sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 3).

5.5.2 Information for Proper Application

Table 3 lists the many considerations applicable to a dredging project. Key factors include:

- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Obstructions or other factors that limit access to soft sediments by the hydraulic dredge
- Containment area features and routing of the slurry to the containment area
- Discharge location and water quality for supernatant from the containment area
- Monitoring to track system recovery and overall project impacts

5.5.3 Factors Favoring the Use of this Technique

- There is a distinct need for increased depth or volume in the lake
- Studies have demonstrated the impact of internal loading on the lake
- The presence of contaminants that are impacting lake biota or uses
- Rooted plants and/or algal mats dependent on the soft sediments are impairing uses
- Sediments are "clean", based on regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake

Table 3. Key Considerations for Dredging

Reasons For Dredging:
Increased depth/access
Removal of nutrient reserves
Control of aquatic vegetation
Alteration of bottom composition
Habitat enhancement
Reduction in oxygen demand

Volume Of Material To Be Removed:
In-situ volume to be removed
Distribution of volume among sediment types
Distribution of volume over lake area (key sectors)
Bulked volume (see below)
Dried volume (see below)

Nature of Underlying Material To Be Exposed:
Type of material
Comparison with overlying material

Dewatering Capacity of Sediments:
Dewatering potential
Dewatering timeframe
Methodological considerations

Protected Resource Areas:
Wetlands
Endangered species
Habitats of special concern
Species of special concern
Regulatory resource classifications

Equipment Access:
Possible input and output points
Land slopes
Pipeline routing
Property issues

Potential Disposal Sites:
Possible containment sites
Soil conditions
Necessary site preparation
Volumetric capacity
Property issues
Long term disposal options

Existing and Proposed Bathymetry:
Existing mean depth
Existing maximum depth
Proposed distribution of lake area over depth
Proposed mean depth
Proposed maximum depth
Proposed distribution of area over depth ran

Physical Nature of Material To Be Remov
Grain size distribution
Solids and organic content
Settling rate
Bulking factor
Drying factor
Residual turbidity

Chemical Nature of Material To Be Remov
Metals levels
Petroleum hydrocarbon levels
Nutrient levels
Pesticides levels
PCB levels
Other organic contaminant levels
Other contaminants of concern (site-specific

Flow Management:
System hydrology
Possible peak flows
Expected mean flows
Provisions for controlling water level
Methodological implications

Relationship To Lake Uses:
Impact on existing uses during project
Impact on existing uses after project
Facilitation of additional uses

Dredging Methodologies:
Hydraulic (or pneumatic) options
Wet excavation
Dry excavation

Table 3 (continued). Key Considerations for Dredging

Applicable Regulatory Processes:	Removal Costs:
NEPA review/Environmental impact reporting	Engineering and permitting costs
Any wetlands protection permitting	Construction of containment area
Any dredging permits	Equipment purchases
Any aquatic structures permits	Operational costs
Any drawdown notification	Contract dredging costs
Clean Water Act Section 401 (WQ certification)	Ultimate disposal costs
Clean Water Act Section 404 (USACE wetlands)	Monitoring costs
Dam safety/alteration permit	Total cost divided by volume to be removed
Any waste disposal permit	
Discharge permits (NPDES, USEPA/state)	
Uses Or Sale Of Dredged Material:	**Other Mitigating Factors:**
Possible uses	Necessary watershed management
Possible sale	Ancillary project impacts
Target markets	Economic setting
	Political setting
	Sociological setting

5.5.4 Performance Guidelines for Swift Creek Reservoir

- Address the many considerations for dredging provided in Table 3; pay particular attention to sediment quality, quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Dredge in accordance with all permits
- Achieve a depth (light) or substrate (hard bottom) limitation to control plant growth; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 feet, whichever comes first
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor containment area discharge quality during hydraulic dredging
- Monitor downstream flows and water quality during hydraulic dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals after dredging

5.6 Application of Fluridone

5.6.1 How This Method Works

Fluridone is a systemic herbicide that comes in two general formulations, an aqueous suspension and a slow release pellet, although several forms of pellets are now on the market. This chemical inhibits carotene synthesis, which in turn exposes the chlorophyll to photodegradation. Most plants can be damaged by sunlight in the absence of protective carotenes, resulting in chlorosis of tissue and death of the entire plant with prolonged exposure to a sufficient concentration of fluridone. When carotene is absent the plant is unable to produce the carbohydrates necessary to sustain life. Some plants, including Eurasian watermilfoil, are more sensitive to fluridone than others, allowing selective control at low doses.

For susceptible plants, lethal effects are expressed slowly in response to treatment with fluridone. Existing carotenes must degrade and chlorosis must set in before plants die off; this takes several weeks to several months, with 30-90 days given as the observed range of time for die off to occur after treatment. The slow rate of plant die-off minimizes the risk of oxygen depletion. Fluridone concentrations should be maintained in the lethal range for the target species for at least 6 weeks, preferably 9 weeks, and ideally 13 weeks. This presents some difficulty for treatment in areas of substantial water exchange.

If the recommended contact time can be achieved, the use of the liquid formulation of fluridone in a single treatment has been very effective. Where dilution is potentially significant, the slow release pellet form of fluridone has been applied, but in highly organic, loose sediments a phenomenon termed “plugging” has been observed, resulting in a failure of the active ingredient to be released from the pellet in a predictable manner. New pellet formulations are intended to avoid this problem. Multiple sequential treatments with the liquid formulation can be used in areas with extremely soft sediments and significant flushing. It may also be possible to sequester a target area with limno-curtains to reduce dilution effects in the target area.

The selectivity of fluridone for the target species depends on the timing and the rate of application. Early treatment (April/early May) with fluridone effectively controls overwintering perennials before some of the beneficial species of pondweed and naiad begin to grow. Variability in response has also been observed as a function of dose, with lower doses causing less impact on non-target species. However, lesser impact on target plants has also been noted in some cases, so dose selection involves balancing risk of failure to control target plants with risk of impact to non-target species.

Maximum label application rates are 8 lb per acre-foot and 0.4 quarts per acre-foot for the Sonar SRP and Sonar AS formulations, respectively. The maximum concentrations of fluridone expected would be 0.15 ppm, but since the mid-1990s it has been extremely rare to have a target concentration greater than 0.02 ppm (20 ppb). Hydrilla can be killed with <10 ppb; only the most sensitive non-target vegetation would be impacted, which includes only the waterweed in Swift Creek Reservoir.

Fluridone is considered to have low toxicity to invertebrates, fish, other aquatic wildlife, and mammals, including humans. The USEPA has set a tolerance limit of 0.15 ppm for fluridone or its degradation products in potable water supplies, although some state restrictions are lower. Substantial bioaccumulation has been noted in certain plant species, but not in animals. The LC50 for sensitive fish species is 7.6 ppm, which is 50 times higher than the expected maximum concentration and about 500 times higher than typical doses used today. Fluridone was not found to impact non-target organisms at concentrations of 0.1 to 1.0 ppm. Rat LD50s are >10,000 mg/kg.

Fluridone has been used in drinking water reservoirs at concentrations <20 ppb, with application at least ¼ mile from any active intake. For control of hydrilla, the concentration could be <10 ppb. While actual risk to humans is minimal, the perception of risk may still remain large. Use in a water supply is typically restricted to one-time or very infrequent applications, to get infestations under control. The federal label for SONAR, the most common tradename herbicide using fluridone, is included in Appendix A. The term “label” is an anachronism; it is not what goes on the container, but rather a description of the herbicide with the federal rules under which this herbicide can be applied.

5.6.2 Information for Proper Application

- Knowledge of flow patterns and time of travel from treatment area to water intake locations
- Knowledge of system hydrology and detention time; need to provide adequate contact time
- Mapping of aquatic vegetation with accurate identification of all species and general appraisal of relative abundance and overall cover/biomass
- Inventory of aquatic biota with emphasis on sensitive species
- Treatment plan to include dose, areas treated, expected alteration of plant community, and follow-up activities
- Tracking of concentration over intended exposure period
- Provision for retreatment if the concentration declines below the effective level before the targeted contact time is achieved
- Monitoring program for assessing effectiveness and impacts

5.6.3 Factors Favoring the Use of this Technique

- Complete kill of targeted submergent vegetation is desired
- The targeted plant has limited dormant propagules (seeds, tubers, winter buds)
- High selectivity for susceptible species is desired
- Long exposure time can be maintained

5.6.4 Performance Guidelines for Swift Creek Reservoir

- Map plant community and note density and distribution of target and non-target species; presence of protected species may limit treatment
- Consider use of granular formulation in areas of hydrilla infestation; limit treatment of uninfested areas
- Apply fluridone product in accordance with label instructions and restrictions; justify dose, location and timing of treatment
- Control flushing in the lake or target areas to maximize exposure time
- Track fluridone levels and add more herbicide as necessary to achieve the needed combination of dose and exposure
- Monitor plant community features before and after treatment

5.7 Grass Carp

5.7.1 How This Method Works

There are several species of fish that consume macrophytes, but the introduction of herbivorous fish generally centers on grass carp (*Ctenopharyngodon idella*). Grass carp are not approved for introduction in all states, but are allowable in Virginia. The grass carp, also known as the white amur, is a species of fish that comes from the Pacific slope of Asia from the Amur River of China and Siberia, south to the West River in southern China and Thailand. They are typically found in low gradient reaches of large river systems. Grass carp can grow to 4 feet long and attain weights of over 100 pounds, making them the largest member of the cyprinid family. They have a very high growth rate, with a maximum at about 6 pounds per year. They typically grow to a size of 15-20 pounds in North American waters and have adapted quite well to life in reservoirs where they are stocked for aquatic vegetation control.

As with other carp species, they are tolerant of wide fluctuations in water quality including water temperatures from 0 to 35^{o}C, salinities up to 10 ppt, and oxygen concentrations approaching 0 mg/L. Grass carp do not feed when water temperatures drop below 11^{o}C (52^{o}F) and feed heavily when water temperatures are between 20^{o}C and 30^{o}C (68^{o}F and 86^{o}F).

Grass carp are believed to have been introduced to the United States in 1963 by the Bureau of Sport Fisheries and Wildlife at the Fish Farming Experimental Station in Stuttgart, Arkansas and Auburn University, Alabama, for research purposes. Expansion of their range since that time has largely been a result of stocking for macrophyte control. In response to the threat of diploid reproduction, a sterile triploid grass carp was first developed for commercial use in 1984. The majority of grass carp currently stocked in North America are sterile triploids, affording control of the population over a period of 5 to 10 years through natural die off.

Dietary preference is an important aspect of grass carp, as pertains to their use as a plant control mechanism. Grass carp have exhibited a wide variety of food choices from study to study. In some cases grass carp have been reported to have a low feeding preference for emergent plants and some invasive submergent plants, but they do eat hydrilla. Generally, grass carp avoid cattails and water lilies, but the high level of variability in grass carp diet among lakes should be kept in mind. In many cases, they seem to eat the desirable native species first and the targeted invasive species later, but the dominance of hydrilla in Swift Creek Reservoir suggests that grass carp will have a substantial amount of hydrilla in their diet.

Fish are usually stocked in the size range of 200 mm to 300 mm (8 to 12 inches). Effective grass carp stocking rates are a function of grass carp mortality, water temperature, plant species composition, plant biomass and desired level of control. The most common stocking rates are greater than 10 to 15 fish per acre for plant eradication and 6 to 10 fish per acre for plant control. Stocking rates in New York average 12.7 fish per acre, but feeding rates are lower in colder water.

In Virginia, the stocking of grass carp is permitted and stocking recommendations for private ponds suggest target densities of fish depending upon the degree of coverage of nuisance plants. Where a waterbody has nuisance plant growth over 30 to 60% of its area, a stocking rate of 5 fish per acre of total waterbody is suggested. Lower degrees of infestation link to a stocking rate of 2 fish/acre, while higher coverage is tied to a stocking rate of 10 fish/acre. Up to 15 fish per acre can be allowed, with elimination of vegetation expected at high stocking levels. Experience in Virginia indicates that once control is achieved, a population of grass carp that equates to 5 fish per acre will maintain low vegetation density.

The fish usually live ten or more years but the typical plant control period is reported to be 3 to 4 years with some restocking often required. In most cases, no major impact is observed for about a year, after which four years of detectable plant decrease is observed. Effects beyond five years are variable without additional stocking. Grass carp are difficult to capture and remove unless the lake is treated with rotenone that will kill other fish species as well.

Grass carp may decrease the density or even eliminate vascular plants, including desirable forms such as nitella, coontail and various pondweeds. Algal blooms resulting from nutrients being converted from plant biomass by the grass carp have been common, even without elimination of vascular plants. In light of the uncertainty associated with this technique and difficulties associated with non-native species introductions, caution should be exercised. However, with sterile triploid stock and a reservoir already dominated by hydrilla, grass carp represent a potential means for control.

Additional experience with grass carp is provided in Appendix B. Included are multiple case histories drawn from various sources; there is no central repository for project summaries of this type, and many sources provide only partial information. From the case histories, it is apparent that hydrilla can be controlled to a limited degree with 5 to 8 fish per vegetated acre of reservoir, and can be severely depressed by fish densities >8 per vegetated acre, with some stocking rates as high as 20 to 30 fish per vegetated acre.

5.7.2 Information for Proper Application

- Knowledge of plant resources and likely impacts of grass carp on them
- Stocking rate that will provide the desired level of control
- Knowledge of nutrient levels, current algal issues, and tolerance for increased bloom frequency or severity
- Contingency planning for at least five years of altered conditions after stocking, including algal bloom control, turbidity control, and habitat management.

5.7.3 Factors Favoring the Use of this Technique

- Domination of reservoir plant community by a species that grass carp will eat
- Ability to keep fish from going upstream or downstream out of the reservoir
- Uses not impaired by algal blooms
- Ability to manage expected non-target impacts from grass carp
- Willingness to wait multiple years for distinct improvement of conditions

5.7.4 Performance Guidelines for Swift Creek Reservoir

- Stock at 5 fish per reservoir acre or up to 15 fish per acre of infested reservoir area to start, with another 5 fish per acre in the third year if warranted by monitoring data
- Evaluate possible outlet area alterations to minimize grass carp escape
- Closely monitor plant community for composition and density
- Closely monitor algal community for composition and density
- Establish thresholds for algal control (currently by copper, consider use of aluminum for nutrient control)

6.0 Recommended Options with Expected Impacts and Costs

6.1 Overview

Any of the above described methods for managing hydrilla has merit for application in Swift Creek Reservoir, but careful consideration of limitations suggests that some may be more applicable and appropriate than others. The following analysis is provided to reach a recommendation of the most prudent course of action.

6.1.1 No action alternative

Although taking no action has not been previously discussed, it is a consideration. If no action was taken to control hydrilla, the remaining portion of the reservoir not yet infested but suitable for colonization (about another 150 acres) will be subjected to hydrilla growths within a few years, but this is likely to occur anyway as the time frame for achieving some level of control is going to be several years. Adverse effects for boaters have already been demonstrated, will continue, and are expected to worsen. Effects on native aquatic species within and around the reservoir are expected to be significant as well. This alternative would also leave the reservoir as a source of hydrilla that could infest other area waterbodies, but it may never be completely devoid of this plant even with the implementation of a control program. Managing spread to other aquatic systems may require aggressive washing of boats entering and leaving the reservoir as a consequence. Overflow of hydrilla from the reservoir to downstream water bodies is another consideration and this may prove unavoidable in the time frame that may be required to achieve some level of control. Even so, failure to take action makes this outcome even more likely. While no substantial impacts to the water supply are projected, there is potential for altered water quality and a related increase in treatment costs. Some form of control program for hydrilla appears warranted.

6.1.2 Benthic barriers

The placement of solid sheeting materials on the reservoir bottom around docks and as access lanes to deeper water is a workable local solution for shoreline homeowners who want access for boats through hydrilla infested waters. It is not a reservoir-wide control strategy, on the basis of cost, maintenance needs and ecological impact if applied on a large scale. Benthic barrier could be placed at nearly any time to facilitate access to deeper water, whereas most other options will require more time to implement. It is not practical to reclaim the large weed-choked areas at the upstream end of the northwestern arm of the reservoir with benthic barrier, however, so hundreds of acres of reservoir area would remain lost to boating use if benthic barrier was the only technique applied. A risk associated with this approach is that it would require human contact with the reservoir to implement.

6.1.3 Mechanical harvesting

Cutting and collecting hydrilla could open areas for boating and limit ecological impacts from the dense growths. One large (10 feet cutting width, 800-100 cubic foot cargo capacity) can handle about 40 to 50 acres of reservoir in a six-week period, about the time it takes for regrowth to require another cutting to maintain open water. With over 700 acres of infested area now and the potential for about 900 acres of infested waters within a few years, an entire fleet of harvesters would be needed to keep up with hydrilla growth in Swift Creek Reservoir. This would seem impractical on a cost basis, but it would be possible to use a harvester much like the benthic barriers, to keep access lanes open. Beyond cutting from shoreline mooring areas to deep water, it might also be possible to maintain some lanes through the dense growths in the upstream portion of the northwestern arm of the reservoir. At least one, and possible two, harvesters would need to operate on a regular basis for at least the growing season, but it is a workable maintenance solution. However, it is not a reservoir-wide control strategy. Additionally, the harvester would be powered by a gasoline engine, presenting some risk of spills.

6.1.4 Drawdown

Lowering the water level has definite potential to kill existing hydrilla plants, and over time could make current areas of excessive growth less hospitable, but there are some difficult aspects of drawdown that require considerable additional assessment before this technique can be recommended. In terms of actual control, the tubers and any seeds that have accumulated in the sediment will be unaffected by drawdown, and if plants produced from those propagules form additional propagules before the next drawdown (which seems very likely), drawdown may be ineffective until sediment features are altered sufficiently to reduce growths (which could take several decades and is not guaranteed). An assessment of tuber density is needed to evaluate the potential for drawdown to reduce hydrilla density. In terms of hydrology, lowering the water level creates the risk that refill will not be completed in time to meet both water supply and recreational demands the following summer. A careful analysis of the range of refill time that corresponds to various drawdown levels under the range of weather conditions expected is needed before this technique can be recommended.

6.1.5 Dredging

Removal of sediment holds the greatest promise of restoring desirable conditions in the reservoir. Plants, root systems, tubers and seeds are all removed, and the uncovered sediment may be less hospitable to future growths. Depth is added, possibly limiting growths through reduced light penetration to the bottom. While ecologically disruptive, dredging can set a reservoir back in time and biological recovery can result in more desirable features. While there are potentially issues with sediment quality that must be evaluated before dredging can be implemented in any aquatic system, there is no current evidence of any sediment quality problems that would prevent dredging of Swift Creek Reservoir. The primary deterrent to dredging is cost.

6.1.6 Fluridone application

Maintaining a concentration of the herbicidal compound fluridone of 6-10 ppb for at least 60 days would kill nearly all of the hydrilla in the reservoir. Getting a 100% kill is very difficult to do under any circumstances, but the maximum damage is done when a lethal concentration of fluridone (>6 ppb) is maintained for most of the growing season. Maintaining the desired concentration is a function of initial and any subsequent inputs of fluridone versus losses due to flushing, photodegradation, and uptake. Monthly booster treatments are typically necessary, as the half-life is normally around 40 days even without flushing, and the maximum concentration that would be applied is 20 ppb. It may be preferable to use a granular formulation that will gradually release fluridone near the target plants and limiting the volume of water treated. Even then, random germination of tubers over the entire year can necessitate repeat treatments over multiple years to gain the desired level of control. Eradication is very rare, and the use of herbicides in drinking water supplies creates negative public perceptions of water quality; herbicide use requires controlled application procedures (see Appendix A). A major public relations campaign with multiple stakeholder meetings would be needed before herbicides could be used in Swift Creek Reservoir. Fluridone provides the fastest means to get initial control over hydrilla, but that control is unlikely to last without follow-up, possibly on an annual basis for multiple years.

6.1.7 Grass carp addition

Stocking herbivorous fish has the potential to reduce hydrilla densities markedly and to keep them low with relatively little maintenance after an initial start up period. With biological controls, however, variability in results can be substantial, and oscillations of target populations are often observed. Getting the right density of grass carp is difficult; too few fish will not achieve control, while too many fish can eliminate all plants (temporarily) and lead to starvation of the fish and loss of control. Stocking over several years to build to the right fish density and set up multiple year classes of fish is a logical course of action. Even if control is achieved, when hydrilla is consumed the fish excrete nutrients that can fuel algal blooms, particularly cyanobacterial blooms. Properly managed, a grass carp program could lower hydrilla density to an acceptable level, but eradication is unlikely and the trade off will be an increased probability of algal blooms. Contingencies for control of algae and management of taste and odor have already been implemented at the water treatment plant and are expected to be capable of addressing any increased treatment needs.

6.2 Additional Consideration of Alternatives

Relatively fast relief for boating access issues could be provided by either benthic barrier placement or a harvesting program. Neither can realistically address the widespread hydrilla problem in Swift Creek Reservoir, but each could allow boats to reach deeper water with less interference from dense hydrilla growths in water less than 8 feet deep. The two approaches are not mutually exclusive, but benthic barriers represent a more property-owner focused approach, while a harvesting program would necessitate some form of cooperative control, at least within development associations if not among all involved parties. The decision on which approach to emphasize will likely be based on some combination of cost and management control, as well as county policies for actions in the reservoir. Human contact and fuel use are primary concerns in this regard.

Of the methods that might address the hydrilla problem throughout the reservoir, drawdown appears to represent the least costly, but also the least likely to provide the desired level of control. Unless a hydrologic analysis indicates that the risk of incomplete spring refill is negligible, drawdown seems likely to be applied only as an aid to dry dredging if that approach is pursued. Dredging (dry or hydraulic) would be the most preferable approach from the perspective of complete removal of hydrilla and its propagules, and although a thorough analysis of dredging feasibility would be needed, there is no indication in any of the available data of any technical problem that would preclude dredging. The issue will be cost; if only one foot had to be removed from 736 acres, that would be 736 acre-feet, or 1.2 million cubic yards. A minimum cost of $10/cy suggests a total cost of at least $12 million. A cost twice that much is not hard to envision, making dredging very difficult to support.

The remaining two approaches, fluridone treatment and grass carp stocking, represent far less cost than dredging and a far greater probability of relief over all areas affected by dense hydrilla than drawdown. As such, either is worth applying at Swift Creek Reservoir, although these two options are to some extent mutually exclusive. Fluridone would be best applied as a granular formulation to dense beds, although initial treatment of a larger area with a liquid formulation at up to 20 ppb might be considered. The primary problem with herbicide use will be public perception of drinking water quality after treatment, even though fluridone is used in potable supplies (see Appendix A). Grass carp would be stocked at up to 15 fish per infested acre the first year, with more fish possibly added in the third year, depending upon assessment of results from the first two years. There are reliability and delayed response issues with using grass carp, along with the likely loss of some native vegetation, and an increase in algal blooms should be expected. However, as the grass carp are sterile, there is a finite duration (no more than 10 years) to the experiment unless stocking is continued.

Narrowing the choices to benthic barriers or harvesting for access support until larger scale control can be achieved and fluridone treatment or grass carp stocking for that systemwide control, an assessment of costs is in order.

6.2.1 Cost of benthic barriers

Assuming that a non-porous barrier would be used, preventing rooting of plants through it and limiting maintenance needs, a material such as hypalon or palco liner would be applied. Current costs for non-porous liners appropriate for this purpose are on the order of $0.60/sq.ft. Note that simple polyethylene sheeting or similar materials have been used at lesser cost ($0.25/sq.ft.), but are less durable, less negatively buoyant, and require more labor to place and maintain. There are approximately 150 shoreline properties currently impacted, and another 100 or so that could be impacted in the near future. Assuming that each of 250 property owners applied 1000 square feet of barrier, the total of 250,000 square feet would carry a liner material cost of $150,000.

Each 1000 square feet of liner will require about 10 rebar pieces or 20 patio blocks to anchor, at a cost of about $40. This adds $10,000 of material cost. Installation labor could come from volunteers, although some training and supervision is advised. Assuming the material is placed on a contract basis at $10,000/acre, the labor cost would be about $60,000. This suggests a total installation cost of $220,000. The amount of barrier per property could be an overestimate for some properties, but could be inadequate for properties in the portion of the reservoir that hosts dense hydrilla over large expanses, unless all property owners participate and a shoreline open water band is created to allow boats to move laterally until they can move out into open water.

Maintenance would most likely be limited to resetting barrier that billows up from trapped gas or gets covered by too much sediment. The barrier under consideration is very durable and should not have to be replaced for over a decade, but a small allowance of $10,000 is allocated over a decade for materials. Assuming that five days of maintenance effort are needed each year by a crew of two, at a cost of $2000/day, an annual cost of $10,000 is derived for maintenance. Maintenance for a decade would therefore cost $100,000, and the total cost for a benthic barrier program for a ten year period is estimated at $330,000.

6.2.2 Cost of mechanical harvesting

While a fleet of harvesters would be needed to cut all hydrilla-infested areas, the envisioned program would just maintain access to deeper water, much like the benthic barrier program. Assuming the same area to be cut for access only (about 6 acres), a single harvester would suffice, and could also maintain some channels through dense areas in the upstream portion of the northwestern arm of the reservoir. To minimize cutting time and related labor costs, a large harvester with a cutting width of nine or ten feet and a hopper capacity of at least 800 cubic feet would be needed. A trailer for transport is also needed, as is a conveyor for offloading at the shoreline. If shoreline offloading areas cannot be designated in the portion of the reservoir where hydrilla is present, a transport barge might also be needed to keep the harvester cutting while loads of plants are ferried to shore at greater distance. However, clearing six acres of access lanes and even a few channels through dense offshore hydrilla would allow time for offloading, as long at the distance to the offloading area is not extreme.

An appropriate harvester will cost about $130,000 delivered, with the trailor costing another $17,000 to $35,000, depending on options selected. The shore conveyor will cost between $30,000 and $40,000, also depending upon selected options. Assuming no transport barge is needed, and one could be added later at no cost disadvantage if so desired, the total capital cost would be $177,000 to $205,000; a value of $200,000 will be assumed in further calculations.

Operational costs will be substantial. A single operator can manage the whole system, including offloading, and could even haul away the accumulated plants at the end of the day. A second person can be helpful, but should not be needed and is not incorporated into this estimate. Local prevailing wage rates will most likely apply, but a general assumption of $50,000 loaded labor cost for a six month harvesting period during each year is assumed. The operator will not need to run the harvester every day, but funds will be needed for routine maintenance, whether by the operator or someone else. Fuel and related costs are estimated at $2,000/year. Material costs for maintenance are typically <$3,000 per year early on, and escalate after about a decade, with harvesters tending to last about 20 years before replacement is necessary (although some have been operated for up to 30 years).

Projecting costs for a decade of operation, mechanical harvesting would cost about $750,000. This is over twice the benthic barrier cost, and requires substantial activity each year, but also provides greater flexibility of application and would be able to control hydrilla over a larger area than benthic barriers can. Over a six week period a harvester like that envisioned for this program could cut hydrilla over about 40 to 50 acres. So while the cost of a harvester to do what is perceived as the maximum area addressed by benthic barriers is higher by a factor of 2.3, the benefit over a decade is about seven times as large.

Alternatively, if reservoir users want to contract for the harvesting operation, a more exact match for the benthic barrier program could be derived. The contract rate tends to vary with plant density, and the hydrilla growths in Swift Creek Reservoir will command a cost near the high end of the range, around $1500/acre, all inclusive. The minimum are needing attention is about six acres, so each cutting would cost $9,000. Cutting will be needed at least once per six weeks for at least the six-month growing season, for an annual contracted cost of about $40,000, exclusive of any disposal costs. Most harvested plants are composted at municipal facilities or on farms at very little cost. For a ten-year period, a cost of $400,000 is estimated, just slightly more than the cost of benthic barriers, although variability in contract harvesting costs can be substantial and the cost estimate is not as certain as that for benthic barriers. Bear in mind that the envisioned contract harvesting is just to maintain open boat access channels; contracting for the level of harvesting that could be conducted if a harvester was purchased and operated by a group at the reservoir would cost about $2.4 million over a decade.

6.2.3 Cost of fluridone treatment

The cost of a fluridone treatment is somewhat difficult to estimate without many assumptions. Key considerations are liquid vs. granular formulation, number of booster treatments, and number of consecutive years in which treatment is needed. Based on negative public perceptions of potable water bodies subjected to herbicide treatments, it is assumed that treatments will be restricted to the infested areas, requiring granular applications, and that treatment will be conducted for only three years or three successive treatments over whatever period of time it takes. This may be inadequate, given the seemingly random germination of hydrilla seeds and tubers over multiple years following the initiation of control efforts. However, based on these premises, each treatment of 736 acres will cost about $1,000/acre, or $736,000 total. Monitoring of fluridone is essential to assess treatment effects, and will cost about $12,000/year or treatment cycle. So for a control program as outlined, the total projected cost would be about $2.2 million. However, this does not include any increased treatment cost associated with any increase in organic matter in the water from dying plants.

6.2.4 Cost of grass carp stocking

The grass carp program as outlined would involve stocking up to 15 fish per infested acre in the first year, followed by up to 5 fish per infested acre in the third year, with the exact number based on assessment of first year impacts and any change in the number of infested acres. Working from the Virginia guidance for grass carp stocking, the stocking rate would be 5 fish per acre for 1700 acres (8,500 fish) or 15 fish per infested acre for the currently infested 736 acres (11,040 fish). It would be better to add fewer fish to begin with, and build the population as needed based on monitoring results, so an initial stocking of 8,500 fish is assumed. If the initial stocking is successful, the density of plants will decline, but the number of infested acres may actually increase as a function of continued expansion of hydrilla to all possible areas within the reservoir. For costing purposes, it is also assumed that 900 acres will have some hydrilla and that 5 fish per infested acre will be stocked in the third year, representing another 4,500 fish. Further, a successful program over a ten-year period would require at least one more stocking, probably in the seventh or eighth year, also assumed at 4,500 fish.

A total stocking of 17,500 grass carp over a ten year period is therefore assumed. Individual fish cost $5 to $15, depending on size and shipping considerations, with larger fish subject to less predation. Assuming $10 per 12-inch fish, the total of 17,500 fish over ten years would cost $175,000. Monitoring of the grass carp population for survival and growth would be prudent, at a cost of about $10,000 every other year, beginning at the end of the first year. So the total cost for a decade-long program would be approximately $225,000.

As an increase in algal bloom frequency is expected with grass carp stocking at the level necessary to control hydrilla, some contingency fund to cover algal control is warranted. Copper-based algaecides are used now, but not very frequently, and cost no more than about $25/acre, with only part of the reservoir treated. Increased copper use may favor resistant forms of algae, many of which are also taste and odor producers, and some of which are toxin formers, so overuse of copper is to be avoided. Occasional use of aluminum compounds to reduce nutrient levels may be another consideration, but carries a higher unit cost, about $100/acre, and potential for adverse effects and regulatory approval need to be considered. Treating the whole reservoir once per year with aluminum compounds would cost about $170,000. Whether or not such a large contingency cost would be included in the hydrilla control cost is a subject for negotiation. Increased treatment costs at the Addison-Evans WTP also need to be considered. Shorter filtration runs before bed regeneration becomes necessary and possible addition of activated carbon would be likely treatment needs at the facility, but specific costs are not known at this time.

6.2.5 Cost Summary

The cost of each option, broken down by year, is provided in Table 4. No permitting or design costs have been included, and no inflation factors have been added. Costs involve assumptions that should be revisited in the planning stage as part of the development of an implementation program. Table 4 is provided to facilitate the most straightforward comparison of approaches based on cost alone.

Table 4. Cost comparison for selected hydrilla management alternatives.

Approach	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Benthic barriers	231,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	330,000
Contract harvesting	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	400,000
Owned harvesting	255,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	750,000
Drawdown	0	0	0	0	0	0	0	0	0	0	0
Dredging	200,000	5,800,000	6,000,000	0	0	0	0	0	0	0	12,000,000
Fluridone herbicide	736,000	736,000	736,000	?	?	?	?	?	?	?	2,208,000
Grass carp	85,000	10,000	45,000	10,000		10,000	45,000	10,000		10,000	225,000

The benefit derived from each option in Table 4 is not identical, and side effects vary as well, but derived costs do facilitate some decisions. It is evident that dredging is so much more expensive than all other alternatives (and the cost shown is the low end of the expected range) that one or more of the others should be tried before resorting to a dredging program. Drawdown, while virtually free in terms of capital cost and designated operational expense, carries risks that could be very costly and could interfere with the very uses the program is intended to protect. Grass carp represent the least expensive alternative after drawdown, but no cost for algae control or additional water treatment is included, and may be needed with this option. Treatment with fluridone was assumed to be allowable for no more than three consecutive years, but is not guaranteed to be allowable for those three years or effective after three years if it is allowed. As fluridone use is the second most expensive option, and presents additional challenges, it is unlikely to be pursued further. Contract harvesting offers comparable benefit to benthic barriers with greater flexibility and fewer issues for reservoir management policy, at only a slightly higher cost. Considerably greater benefit might be derived from owning and operating a harvester, but at substantially greater cost. A combination of effectiveness, feasible application and cost should be applied in making a decision on the approach to be taken.

6.3 Recommendations

Although a case can be made for each option described, and each has drawbacks that should be covered with contingency planning, the combination of effectiveness, flexibility, maintenance needs, feasibility of application, planning and permitting considerations, and cost suggests that operation of a harvester would be appropriate to provide shorter term and localized relief, while stocking of grass carp offers the best option for longer term control. Ideally, the harvesting program would become a less important support back up to grass carp control of hydrilla after no more than five years, reducing operation and maintenance costs for the harvesting option.

Based on the grass carp program cost and a contract harvesting program that would run for 5 years before becoming unnecessary as a function of grass carp control of hydrilla, a ten year cost of $425,000 is estimated. If a harvester was purchased, there would be greater benefits in the initial years when control was most needed, but the cost would rise to $700,000. After 5 years there would be a harvester available for use as needed, or for resale. Initial purchase of a harvester would be advised only if acceptable contract services were unavailable. Note that these estimates do not include any costs for control of algal blooms or increased treatment needs at the water treatment facility, an expected consequence of grass carp stocking and an important consideration for the County water supply operation.

7.0 Five-Year Strategy

Assuming that the above analysis is accepted, the five year program would include:

1. Form an overall reservoir management group, representing all interest groups that use the reservoir, to guide future management efforts directed at reducing hydrilla abundance.
2. Assuming approval can be obtained for use of a mechanical harvester on Swift Creek Reservoir, contract for harvesting services for the first two years, to determine the level of satisfaction this provides.
3. Assuming that fish are available and funding and permits can be obtained, stock 8,500 triploid grass carp of approximately one foot in length as soon as possible.
4. Monitor hydrilla distribution and density annually, and assess the native plant community as well.
5. Monitor algal community composition and abundance weekly to twice per month; be prepared to take actions to reduce nutrients or algae in the reservoir or enhance treatment at the Addison-Evans WTP.
6. Evaluate grass carp growth and survival after the first year and compare with hydrilla reduction over the first two years, and determine if additional stocking is warranted. If so, stock up to 4,500 more grass carp in the third year.
7. Evaluate the contract harvesting program after two years and determine if a change in approach is needed. If more area should be harvested and the indication is that grass carp are not yet providing the desired level of control, consider purchase of a harvester and development of a harvesting program run by the reservoir management group.
8. Continue annual monitoring of the plant community and assess grass carp population features after the third and fifth year.
9. Evaluate ongoing needs and possible program changes during the fifth year and develop the program for the next five years.

8.0 References

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Appendix A: SONAR Label

Specimen Label

SePRO

Sonar A.S.

Herbicide

A herbicide for management of aquatic vegetation in fresh water ponds, lakes, reservoirs, potable water sources, drainage canals and irrigation canals.

Active Ingredient:
fluridone: 1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1*H*)-pyridinone 41.7%
Inert Ingredients 58.3%
Total 100.0%

Contains 4 pounds active ingredient per gallon.

EPA Registration No. 67690-4
EPA Est. 37429-GA-01
FPL 052102

Precautionary Statements

Hazards to Humans and Domestic Animals

Keep Out of Reach of Children

CAUTION PRECAUCION

Si usted no entiende la etiqueta, busqua a alguien para que se la explique a usted en detaile. (If you do not understand this label, find someone to explain it to you in detail.)

Harmful If Swallowed, Absorbed Through Skin, Or If Inhaled

Avoid breathing of spray mist or contact with skin, eyes, or clothing. Wash thoroughly with soap and water after handling. Remove contaminated clothing and wash before reuse.

*Trademark of SePRO Corporation
SePRO Corp. • Carmel, IN 46032 U.S.A.

First Aid	
If in eyes	• Hold Eye open and rinse slowly and gently with water for 15 - 20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. • Call poison control center or doctor for treatment advice.
If on skin or clothing	• Take off contaminated clothing. • Rinse skin immediately with plenty of water for 15 – 20 minutes. • Call a poison control center or doctor for treatment advice.
If swallowed	• Call a poison control center or doctor for treatment advice. • Have person sip a glass of water if able to swallow. • Do not induce vomiting unless told to do so by a poison control center or doctor. • Do not give anything by mouth to an unconscious person.
If inhaled	• Move person to fresh air. • If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably mouth-to-mouth if possible. • Call a poison control center or doctor for further treatment advice.
Have the product container or label with you when calling a poison control center or doctor, or going for treatment	

Environmental Hazards

Follow use directions carefully so as to minimize adverse effects on nontarget organisms. In order to avoid impact on threatened or endangered aquatic plant or animal species, users must consult their State Fish and Game Agency or the U.S. Fish and Wildlife Service before making applications.

Do not contaminate water when disposing of equipment washwaters. Trees and shrubs growing in water treated with Sonar A.S. herbicide may occasionally develop chlorosis. Do not apply in tidewater/brackish water.

Lowest rates should be used in shallow areas where the water depth is considerably less than the average depth of the entire treatment site, for example, shallow shoreline areas.

Directions for Use

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.
Read all Directions for Use carefully before applying.

Sonar* A.S. Herbicide

Shake well before using.

Storage and Disposal

Do not contaminate water, food, or feed by storage or disposal.

Storage: Store in original container only. Do not store near feed or foodstuffs. In case of leak or spill, use absorbent materials to contain liquids and dispose as waste.

Pesticide Disposal: Wastes resulting from use of this product may be used according to label directions or disposed of at an approved waste disposal facility.

Container Disposal: Triple rinse (or equivalent). Then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

General Information

Sonar A.S. herbicide is a selective systemic aquatic herbicide for management of aquatic vegetation in fresh water ponds, lakes, reservoirs, drainage canals and irrigation canals. Sonar A.S. is absorbed from water by plant shoots and from hydrosoil by the roots of aquatic vascular plants. It is important to maintain the recommended concentration of Sonar A.S. in contact with the target plants for a minimum of 45 days. Rapid water movement or any condition which results in rapid dilution of Sonar A.S. in treated water will reduce its effectiveness. In susceptible plants, Sonar A.S. inhibits the formation of carotene. In the absence of carotene, chlorophyll is rapidly degraded by sunlight. Herbicidal symptoms of Sonar A.S. appear in seven to ten days and appear as white (chlorotic) or pink growing points. Under optimum conditions, 30 to 90 days are required before the desired level of aquatic plant management is achieved with Sonar A.S. Species susceptibility to Sonar A.S. may vary depending on time of year, stage of growth, and water movement. For best results, apply Sonar A.S. prior to initiation of weed growth or when weeds begin active growth.

Application to mature target plants may require higher application rates and may take longer to control.

Sonar A.S. is not corrosive to application equipment.

The label provides recommendations on the use of a chemical analysis for the active ingredient. SePRO Corporation recommends the use of an Enzyme-Linked Immunoassay (ELISA Test) for the determination of the active ingredient concentration in the water. Contact SePRO Corporation for the utilization of this test, known as FasTEST, for the incorporation of this analysis in your treatment program. Other proven chemical analysis for the active ingredient may also be used. The chemical analysis, FasTEST, is referenced in this label as the preferred method for the rapid determination of the concentration of the active ingredient in the water.

Application rates are provided in ounces or quarts of Sonar A.S. to achieve a desired concentration of the active ingredient in parts per billion (ppb). The maximum application rate or sum of all application rates is 90 ppb in ponds and 150 ppb in lakes and reservoirs per annual growth cycle. This maximum concentration is the amount of product calculated as the target application rate, NOT determined by testing the residues of the active ingredient in the treated water.

General Use Precautions

- **Obtain Required Permits:** Consult with appropriate state or local water authorities before applying this product. Permits may be required by state or local public agencies.
- **Chemigation:** Do not apply Sonar A.S. through any type of irrigation system.
- **Hydroponic Farming:** Do not use Sonar A.S. treated water for hydroponic farming.
- **Greenhouse and Nursery Plants:** Do not use Sonar A.S. treated water for irrigating greenhouse or nursery plants. Use of an approved assay should confirm that residues are <1 ppb.
- **WATER USE RESTRICTIONS FOLLOWING APPLICATIONS WITH SONAR A.S. (DAYS)**

Application Rate	Drinking†	Fishing	Swimming	Livestock/Pet Consumption	Irrigation††
Maximum Rate (150 ppb) or less	0	0	0	0	See irrigation instructions below

† Note below, under Potable Water Intakes, the information for application of Sonar A.S. within 1/4 mile (1320 feet) of a functioning potable water intake.

†† Note below, under Irrigation, specific time frames or fluridone residues that provide the widest safety margin for irrigating with fluridone treated water.

- **Potable Water Intakes:** In lakes and reservoirs or other sources of potable water, DO NOT APPLY Sonar A.S. at application rates greater than 20 ppb within one-fourth mile (1320 feet) of any functioning potable water intake. At application rates of 6-20 ppb, Sonar A.S. MAY BE APPLIED where functioning potable water intakes are present. **Note: Existing potable water intakes which are no longer in use, such as those replaced by potable water wells or connections to a municipal water system, are not considered to be functioning potable water intakes.**

- **Irrigation:** Irrigation from a Sonar A.S. treated area may result in injury to the irrigated vegetation. SePRO Corporation recommends following the precautions and informing those who irrigate from areas treated with Sonar A.S. of the irrigation time frames or water assay requirements presented in the table below. These time frames and assay recommendations are suggestions which should be followed to reduce the potential for injury to vegetation irrigated with water treated with Sonar A.S. Greater potential for crop injury occurs where Sonar A.S. treated water is applied to crops grown on low organic and sandy soils.

	Days After Application		
Application Site	**Established Tree Crops**	**Established Row Crops Turf/Plants**	**Newly Seeded Crops/Seedbeds or Areas to be Planted Including /Overseeded Golf Course Greens**
†Ponds and Static Canals	7	30	Assay required
Canals	7	14	Assay required
††Lakes and Reservoirs	7	14	Assay required

†For purposes of Sonar A.S. labeling, a pond is defined as a body of water 10 acres or less in size. A lake or reservoir is greater than 10 acres.
††In lakes and reservoirs where one-half or greater of the body of water is treated, use the pond and static canal irrigation precautions.

Where the use of Sonar A.S. treated water is desired for irrigating crops prior to the time frames established above, the use of FasTEST assay is recommended to measure the concentration in the treated water. Where FasTEST has determined that the concentrations are less than 10 parts per billion, there are no irrigation precautions for irrigating established tree crops, established row crops or turf. For tobacco, tomatoes, peppers or other plants within the Solanaceae Family and newly seeded crops or newly seeded grasses such as overseeded golf course greens, do not use Sonar A.S. treated water if measured fluridone concentrations are greater than 5 ppb. Furthermore, when rotating crops, do not plant members of the Solanceae family in land that has been previously irrigated with fluridone concentrations in excess of 5 ppb. It is recommended that an aquatic specialist be consulted prior to commencing irrigation of these sites.

Plant Control Information

Sonar A.S. selectivity is dependent upon dosage, time of year, stage of growth, method of application and water movement. The following categories, controlled, partially controlled, and not controlled are provided to describe expected efficacy under ideal treatment conditions using higher to maximum label rates. Use of lower rates will increase selectivity of some species listed as controlled or partially controlled. Additional aquatic plants may be controlled, partially controlled, or tolerant to Sonar A.S. Consult an aquatic specialist prior to application of Sonar A.S. to determine a plant's susceptibility to Sonar A.S.

Vascular Aquatic Plants Controlled by Sonar A.S.

Floating Plants:
common duckweed (*Lemna minor*)

Emersed Plants:
spatterdock (*Nuphar luteum*)
water-lily (*Nymphaea* spp.)

Submersed Plants:
bladderwort (*Utricularia* spp.)
common coontail (*Ceratophyllum demersum*)
common elodea (*Elodea canadensis*)
egeria, Brazilian elodea (*Egeria densa*)
fanwort, cabomba (*Cabomba caroliniana*)
hydrilla (*Hydrilla verticillata*)
naiad (*Najas* spp.)
pondweed (*Potamogeton* spp., except Illinois pondweed)
watermilfoil (*Myriophyllum* spp., except variable-leaf milfoil)

Shoreline Grasses:
paragrass (*Urochloa mutica*)

Vascular Aquatic Plants Partially Controlled by Sonar A.S.

Floating Plants:
common watermeal (Wolffia columbiana)†

Emersed Plants:
alligatorweed (*Alternanthera philoxeroides*)
American lotus (*Nelumbo lutea*)
cattail (*Typha* spp.)
creeping waterprimrose (*Ludwigia peploides*)
parrotfeather (*Myriophyllum aquaticum*)
smartweed (*Polygonum* spp.)
spikerush (*Eleocharis* spp.)
waterpurslane (*Ludwigia palustris*)
watershield (*Brasenia schreberi*)

Submersed Plants:
Illinois pondweed (*Potamogeton illinoensis*)
limnophila (*Limnophila sessiliflora*)
tapegrass, American eelgrass (*Vallisneria americana*)
watermilfoil-variable-leaf milfoil (*Myriophyllum heterophyllum*)

Shoreline Grasses:
barnyardgrass (*Echinochloa crusgalli*)
giant cutgrass (*Zizaniopsis miliacea*)
reed canarygrass (*Philaris arundinaceae*)
southern watergrass (*Hydrochloa caroliniensis*)
torpedograss (*Panicum repens*)
†Partial control only with Sonar A.S. applied at the maximum labeled rate.

Vascular Aquatic Plants <u>Not Controlled</u> by Sonar A.S.

Floating Plants:
waterlettuce (*Pistia stratiotes*)

Emersed Plants:
American frogbit (*Limnobium spongia*)
arrowhead (*Sagittaria* spp.)
bacopa (*Bacopa* spp.)
big floatingheart, banana lily (*Nymphoides aquatica*)
bulrush (*Scirpus* spp.)
floating waterhyacinth (*Eichhornia crassipes*)
pickerelweed, lanceleaf (*Pontederia* spp.)
rush (*Juncus* spp.)
water pennywort (*Hydrocotyle umbellata*)

Shoreline Grasses:
maidencane (*Panicum hemitomon*)

Note: algae (chara, nitella, and filamentous species are not controlled by Sonar A.S.)

Mixing and Application Directions

The aquatic plants present in the treatment site should be identified prior to application to determine their susceptibility to Sonar A.S. It is important to determine the area (acres) to be treated and the average depth in order to select the proper application rate. Do not exceed the maximum labeled rate for a given treatment site per annual growth cycle.

Shake Sonar A.S. well before using. Add the recommended amount of Sonar A.S. to water in the spray tank during the filling operation. Agitate while filling and during spraying. Surface or subsurface application of the spray can be made with conventional spray equipment. Sonar A.S. can also be applied near the surface of the hydrosoil using weighted trailing hoses. A spray volume of 5 to 100 gallons per acre may be used. Sonar A.S. may also be diluted with water and the concentrated mix metered into the pumping system.

Tank Mix Recommendations

Sonar A.S. may be tank mixed with other aquatic herbicides and algaecides to enhance efficacy and plant selectivity. Refer to the companion herbicide or algaecide label for use directions, precautions, and restrictions on use.

Application to Ponds

Sonar A.S. may be applied to the entire surface area of a pond. For single applications, rates may be selected to provide 45 to 90 ppb to the treated water. Use the higher rate within the rate range where there is a dense weed mass, when treating more difficult to control species, and for ponds less than 5 acres in size with an average depth less than 4 feet. Application rates necessary to obtain these concentrations are shown in the following table. For additional application rate calculations, refer to page 6—Application Rate Calculation-Ponds, Lakes and Reservoirs. Split or multiple applications are recommended where dilution of treated water is anticipated; however, the sum of all applications must not exceed a total of 90 ppb per annual growth cycle.

Average Water Depth of Treatment Site (feet)	Quarts of Sonar A.S. per Treated Surface Acre to Achieve: 45 ppb	to 90 ppb	Fluid Ounces of Sonar A.S. Per Treated Surface Acre to Achieve: 45 ppb	to 90 ppb
1	0.12	0.24	3.8	7.7
2	0.24	0.49	7.7	15.7
3	0.37	0.73	11.8	23.4
4	0.49	0.98	15.7	31.4
5	0.61	1.22	19.5	39.0
6	0.73	1.46	23.4	46.7
7	0.85	1.70	27.2	54.4
8	0.98	1.95	31.4	62.4
9	1.10	2.19	35.2	70.1
10	1.22	2.44	39.0	78.1

Application to Lakes and Reservoirs

The following treatments are recommended for treating both whole lakes or reservoirs and partial areas of lakes or reservoirs (bays, etc.). For best results in treating partial lakes and reservoirs, Sonar A.S. treatment areas should be a minimum of 5 acres in size. Treatment of areas smaller than 5 acres or treatment of narrow strips such as boat lanes or shorelines may not produce satisfactory results due to dilution by untreated water. Rate ranges are provided as a guide to include a wide range of environmental factors, such as, target species, plant susceptibility, selectivity and other aquatic plant management objectives. Application rates and methods should be selected to meet the specific lake/reservoir aquatic plant management goals.

A. Whole Lake or Reservoir Treatments (Limited or No Water Discharge)

1. Single Application to Whole Lakes or Reservoirs
Where single applications to whole lakes or reservoirs are desired, apply Sonar A.S. at an application rate of 10 to 90 ppb. Application rates necessary to obtain these concentrations in treated water are shown in the following table. For additional rate calculations, refer to page 6—Application Rate Calculation-Ponds, Lakes, and Reservoirs. Choose an application rate to meet the aquatic plant management objective. **Where greater plant selectivity is desired such as when controlling Eurasian watermilfoil and curlyleaf pondweed, choose an application rate lower in the rate range.** For other plant species, SePRO recommends contacting an aquatic specialist in determining when to choose application rates lower in the rate range to meet specific plant management goals. Use the higher rate within the rate range where there is a dense weed mass or when treating more difficult to control plant species. Retreatments may be required to control more difficult to control species or in the event of a heavy rainfall event where dilution of the treatment concentration has occurred. In these cases, a second application or more may be required; however, the sum of all applications cannot exceed 150 ppb per annual growth cycle. Refer to the following Section (No. 2) Split or Multiple Applications for guidelines and maximum rate allowed.

Single Application of Sonar A.S.

Average Water Depth of Treatment Site (feet)	Quarts of Sonar A.S. per Treated Surface Acre to Achieve:			Fluid Ounces of Sonar A.S. Per Treated Surface Acre to Achieve:		
	10 ppb	to	90 ppb	10 ppb	to	90 ppb
1	0.03		0.24	1.0		7.7
2	0.05		0.49	1.6		15.7
3	0.08		0.73	2.6		23.4
4	0.11		0.98	3.2		31.4
5	0.14		1.22	4.5		39.0
6	0.16		1.46	5.1		46.7
7	0.19		1.70	6.1		54.4
8	0.22		1.95	7.0		62.4
9	0.24		2.19	7.6		70.1
10	0.27		2.44	8.6		78.1
11	0.30		2.68	9.6		86.0
12	0.32		2.93	10.2		93.8
13	0.35		3.17	11.2		101.4
14	0.38		3.42	12.1		109.4
15	0.41		3.66	13.1		117.1
16	0.43		3.90	13.8		124.8
17	0.46		4.15	14.7		132.2
18	0.49		4.39	15.7		140.5
19	0.51		4.63	16.3		148.2
20	0.54		4.88	17.3		156.2

2. Split or Multiple Applications to Whole Lakes or Reservoirs

To meet certain plant management objectives, split or multiple applications may be desired in making whole lake treatments. Split or multiple application programs are desirable when the objective is to use the minimum effective dose and, through the use of a water analysis, e.g. FasTEST, add additional Sonar A.S. to maintain this lower dose for the sufficient time to ensure efficacy and enhance selectivity. Water may be treated at an initial application of 6 to 50 ppb. Additional split applications should be conducted to maintain a sufficient concentration for a minimum of 45 days or longer. **In controlling Eurasian watermilfoil and curlyleaf pondweed and where greater plant selectivity is desired, choose an application rate lower in the rate range.** For other plant species, SePRO recommends contacting an aquatic specialist in determining when to choose application rates lower in the rate range to meet specific plant management goals. When utilizing split or multiple applications of Sonar A.S., the utilization of FasTEST is strongly recommended to determine the actual concentration in the water over time. For split or multiple applications, the sum of all applications must not exceed 150 ppb per annual growth cycle.

Note: In treating lakes or reservoirs that contain functioning potable water intakes and the application requires treating within 1/4 mile of a potable water intake, no single application can exceed 20 ppb. Additionally, the sum of all applications cannot exceed 150 ppb per annual growth cycle.

B. Partial Lake or Reservoir Treatments

Where dilution of Sonar A.S. with untreated water is anticipated, such as in partial lake or reservoir treatments, split or multiple applications may be used to extend the contact time to the target plants. The application rate and use frequency of Sonar A.S. in a partial lake is highly dependent upon the treatment area. Higher application rates may be required and frequency of applications will vary depending upon the potential of untreated water diluting the Sonar A.S. concentration in the treatment area. Use higher rates where greater dilution with untreated water is anticipated.

1. Treatment Areas Greater Than 1/4 Mile from a Functioning Potable Water Intake

For single applications, apply Sonar A.S. at application rates from 30 to150 ppb. Split or multiple applications may be made; however, the sum of all applications cannot exceed 150 ppb per annual growth cycle. Split applications should be conducted to maintain a sufficient concentration in the target area for a period of 45 days or longer. The use of FasTEST is recommended to maintain the desired concentration in the target area over time.

2. Treatment Areas Within 1/4 Mile of a Functioning Potable Water Intake

In treatment areas that are within 1/4 mile of a potable water intake, no single application can exceed 20 ppb. When utilizing split or multiple applications of Sonar A.S. for sites which contain a potable water intake, FasTEST is required to determine the actual concentration in the water. Additionally, the sum of all applications cannot exceed 150 ppb per annual growth cycle.

Application Rate Calculation - Ponds, Lakes and Reservoirs

The amount of Sonar A.S. to be applied to provide the desired ppb concentration of active ingredient in treated water may be calculated as follows:

Quarts of Sonar A.S. required per treated surface acre =
Average water depth of treatment site (feet)
x Desired ppb concentration of active ingredient
x 0.0027

For example, the quarts per acre of Sonar A.S. required to provide a concentration of 25 ppb of active ingredient in water with an average depth of 5 feet is calculated as follows:

5 **x** 25 **x** 0.0027 = 0.33 quarts per treated surface acre

When measuring quantities of Sonar A.S., quarts may be converted to fluid ounces by multiplying quarts to be measured **x** 32. For example, 0.33 quarts **x** 32 = 10.5 fluid ounces.

Note: Calculated rates should not exceed the maximum allowable rate in quarts per treated surface acre for the water depth listed in the application rate table for the site to be treated.

Application to Drainage Canals and Irrigation Canals

Static Canals:

In static drainage and irrigation canals, Sonar A.S. should be applied at the rate of 1 to 2 quarts per treated surface acre.

Moving Water Canals:

The performance of Sonar A.S. will be enhanced by restricting or reducing water flow. In slow moving bodies of water use an application technique that maintains a concentration of 15-40 ppb in the target area for a minimum of 45 days. Sonar A.S. can be applied by split or multiple broadcast applications or by metering in the product to provide a uniform concentration of the herbicide based upon the flow pattern. The use of FasTEST is recommended to maintain the desired concentration in the target area over time.

Static or Moving Water Canals Containing a Functioning Potable Water Intake

In treating a static or moving water canal which contains a functioning potable water intake, applications of Sonar A.S. greater than 20 ppb must be made more than 1/4 mile from a functioning potable water intake. Applications less than 20 ppb may be applied within 1/4 mile from a functioning potable water intake; however, if applications of Sonar A.S. are made within 1/4 mile of a functioning potable water intake, the FasTEST must utilized to demonstrate that concentrations do not exceed 150 ppb at the functioning potable water intake.

Application Rate Calculation – Moving Water Drainage and Irrigation Canals

The amount of Sonar A.S. to be applied through a metering system to provide the desired ppb concentration of active ingredient in treated water may be calculated as follows:

1. Average flow rate (feet per second) **x** average canal width (ft.) **x** average canal depth (ft.) **x** 0.9 = CFS (cubic feet per second).
2. CFS **x** 1.98 = acre feet per day (water movement)
3. Acre feet per day **x** desired ppb **x** 0.0027 = Quarts of Sonar A.S. required per day

Warranty Disclaimer

SePRO Corporation warrants that this product conforms to the chemical description on the label and is reasonably fit for the purposes stated on the label when used in strict accordance with the directions, subject to the inherent risks set forth below. SEPRO CORPORATION MAKES NO OTHER EXPRESS OR IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR ANY OTHER EXPRESS OR IMPLIED WARRANTY.

Inherent Risks of Use

It is impossible to eliminate all risks associated with use of this product. Plant injury, lack of performance, or other unintended consequences may result because of such factors as use of the product contrary to label instructions (including conditions noted on the label, such as unfavorable temperatures, soil conditions, etc.), abnormal conditions (such as excessive rainfall, drought, tornadoes, hurricanes), presence of other materials, the manner of application, or other factors, all of which are beyond the control of SePRO Corporation or the seller. All such risks shall be assumed by buyer.

Limitation of Remedies

The exclusive remedy for losses or damages resulting from this product (including claims based on contract, negligence, strict liability, or other legal theories), shall be limited to, at SePRO Corporation's election, one of the following:

(1) Refund of purchase price paid by buyer or use for product bought, or

(2) Replacement of amount of product used.

SePRO Corporation shall not be liable for losses or damages resulting from handling or use of this product unless SePRO Corporation is promptly notified of such loss or damage in writing. In no case shall SePRO Corporation be liable for consequential or incidental damages or losses.

The terms of the Warranty Disclaimer above and this Limitation of Remedies cannot be varied by any written or verbal statements or agreements. No employee or sales agent of SePRO Corporation or the seller is authorized to vary or exceed the terms of the Warranty Disclaimer or this Limitation of Remedies in any manner.

Appendix B: Grass Carp Experience

This appendix provides case study reviews from multiple sources and a summary table. In essence, grass carp success is related to the combination of stocking density, usually expressed as number of fish per vegetated acre, the size of the fish stocked (preferred to be at least 10 inches long at stocking), and the species of plants present (preference by grass carp varies by plant species). Hydrilla is high on the preference list for grass carp. Ten-inch fish can be stocked. The stocking density for successful control of hydrilla in other systems has been >8 fish per vegetated acre, with some successful rates as high as 20 to 30 fish per vegetated acre. Partial control has typically been achieved at stocking rates between 5 and 8 fish per vegetated acre where hydrilla has been the target plant.

Lake Anna, VA

Lake Anna is a 9,600-acre cooling water reservoir for Virginia Power that is infested by hydrilla *(Hydrilla verticillata)*. In 1994, the Virginia Power waste heat treatment facility was stocked with grass carp and the carp migrated to Lake Anna. The grass carp were introduced at a density of 20 carp per acre of hydrilla (RTD 2009). Hydrilla abundance rapidly decreased one year after the carp introduction. However, the weather conditions in 1995 did not promote aquatic vegetation, so the decline may not be entirely attributed to grass carp. Small quantities of hydrilla began to re-emerge in 2007 (VDGIF 2007), but control for a decade was observed.

Ball Pond, CT

Ball Pond is an 82.5-acre lake located in New Fairfield, Connecticut. Since 1997, CTDEP stocked a total of 700 sterile triploid grass carp in four stocking events to control Eurasian watermilfoil. That is 8.5 fish per lake acre, but over a decade; with mortality, it is effectively no more than 5 fish per acre. During the 2008 stocking event, CTDEP stocked 75 grass carp (2.2 triploids/ surface ha, or 0.9/ac). The results of a 2005 CTDEP plant survey suggest that the grass carp have controlled *M. spicatum* to a substantial degree (CT DEP 2005), with a 50% reduction in weed biomass since the introduction of grass carp (New Fairfield 2009). *Ceratophyllum demersum* (coontail) is slowly replacing *M. spicatum. C. demersum* and *Najas guadalupensis* were the dominants in Ball Pond in 2005.

Lake Carmel, NY

About 100 acres of this 200 acre lake in Putnam County, NY, north of New York City, was plagued by dense growths of common waterweed (Elodea) and coontail (Ceratophyllum). Densities were 150 to 400 grams per square meter, a high biomass. In 1999, 10 grass carp per vegetated acre (1000 total) were stocked (NYSFOLA 2009). Vegetation biomass declined to 50 to 100 grams per square meter (25 to 33% of pre-stocking density) by 2002, three years after stocking. Water clarity declined somewhat, with more frequent cyanobacterial blooms observed. Largemouth bass average size also decreased.

Lake Conroe, TX
Lake Conroe is an 8,100 hectare water supply impoundment in Texas infested by hydrilla. All plants were eradicated in less than two years after the introduction of grass carp at 33 carp per hectare (13 fish/ac), which represented 74 carp per vegetated hectare (30 fish/vegetated ac) (Cooke *et al*. 2005). Some diploid fish escaped downstream, creating problems for the downstream plant community.

Lake Conway, FL
Lake Conway is a 730-hectare urban impoundment in Florida. Grass carp were stocked at rates of 7.5 to 12.5 fish per hectare (3 to 5 fish/ac) in order to control hydrilla (Cooke *et al*. 2005). The grass carp reduced hydrilla, stonewort, and pondweeds, but did not affect tape grass (*Vallisneria* sp.). Lake Conroe is a case study of the use of low density stocking that almost eliminated all plants. Researchers did not observe the effects from the grass carp until two years following the introduction of the carp.

Deer Point Lake, FL
Deer Point Lake is a 1,900 hectare Florida impoundment infested by *Potamogeton illinoiensis* and *M. spicatum*. Chemical treatment with Hydrothol from 1972-1975 was ineffective in weed control, so 1800 grass carp (22.4 carp per hectare, or 9 per acre) were introduced into the lake in 1978. All submerged plants were eradicated by 1980 and all emergent plants were eradicated by 1982 (Cooke *et al*. 2005).

Lake Gaston, NC
The 20,000-acre Lake Gaston began stocking grass carp for hydrilla control (LGWCC 2009). In 1995, grass carp were stocked in Lake Gaston at a density of 6.5 carp per acre of hydrilla. In 1999, an additional 5,000 carp were stocked; the number per vegetated acre was apparently not recorded. The carp population after a 2003 stocking event was estimated at 25,392, a density of 8 carp per acre of hydrilla. Annual fluridone (SONAR®) treatments began in 1998 and continue presently. According to a 2006 weed control plan, hydrilla coverage has fluctuated around 3,500 acres (Lake Gaston Stakeholder's Board 2005). Grass carp alone appear not to have controlled hydrilla to the desired degree.

Guntersville Reservoir, AL
The Tennessee Valley Authority (TVA) conducted a triploid grass carp demonstration study on the 27,500 ha Guntersville Reservoir to control hydrilla *(Hydrilla verticillata)*, spinyleaf naiad (*Najas major*), and Eurasian milfoil (*Myriophyllum spicatum*) (Webb *et al*., 1994). In 1990, TVA stocked the reservoir with 100,000 triploid grass carp at a density of 17 fish per vegetated hectare (7/ac). It was estimated that the actual fish density in 1990 was 20 fish per vegetated hectare (8/ac) because other local organizations stocked grass carp prior to 1990. Plant cover decreased 65% from 1989 (pre-TVA stocking) to 1991 (post-TVA stocking) and then slowly increased. The carp account for the immediate decline in plant species that carp favor, including native narrowleaf pondweeds, *N.*

major, and *H. verticillata*. Hydrilla did regrow three years following the 1990 stocking. The *M. spicatum* population decreased later (1991), but regrew downstream. Maintenance stocking appears essential for hyrilla control.

Lake James, NC

The North Carolina Wildlife Resources Commission stocked hydrilla infested Lake James with 21,000 carp in 2002 (SCAPMS 2009). Lake James is a 6,812 acre Duke Energy hydropower impoundment in North Carolina. Hydrilla covered 500 acres of the lake in 2002 and 1,400 acres in 2004. The stocking rate was therefore 3 fish per acre or 42 per hydrilla-infested acre, yet hydrilla coverage increased over two years. Density data were not provided, so complete impact on hydrilla is not known.

Lake Mahopac, NY

Dense Eurasian watermilfoil beds extended to a depth of 12-15 ft in 560 acre Lake Mahopac in Putnam County, NY, north of New York City. In 1994 a total of 2565 triploid grass carp were stocked, a rate of 15 fish per vegetated acre (NYSFOLA 2009). A 73% reduction occurred in the first year, with another 13% reduction in the second year. No vegetation was observable in the lake by 2001. Fishing success for large bass declined, but lake use for boating was facilitated.

Lake Norman, NC

The North Carolina Wildlife Resources Commission began stocking triploid grass carp in Lake Norman in 2004 in order to control a hydrilla infestation (Lake Norman Cove Keepers 2009). Prior to the introduction of carp, the hydrilla infestation covered up to 11,520 acres of the 32,475 acre Duke Energy impoundment. In 2004, 6,000 grass carp were stocked in Lake Norman and 1,500 addition carp were added every year following the initial introduction. The North Carolina Wildlife Resources Commission recommended stocking carp at a density up to 20 fish per vegetated acre (Lake Norman Hydrilla Control 2009), but the initial stocking rate was <0.5 fish per vegetated acre. Assuming no mortality and four years of additional stocking, the grass carp density is still only 1 fish/vegetated acre after 2008. No results were provided, but a major impact would not be expected, given the low stocking rate.

Lake Parkinson, New Zealand

Lake Parkinson is a 1.9 hectare lake in New Zealand with the exotic plant, *Egeria densa*, or Brazilian elodea. The exotic plant was eradicated following the introduction of grass carp (Cooke *et al*. 2005). The grass carp were then removed and native aquatic vegetation colonized the lake before exotic species were reestablished.

Santee Cooper Reservoirs, SC

Kirk *et al*. (2000) described the results of a triploid grass carp study in the Santee Cooper reservoirs. Grass carp were introduced into the 70,000 ha Santee Cooper Reservoirs South

Carolina by incremental stocking in order to control *Hydrilla verticillata* (hydrilla). Between 1989 and 1996, 768,500 triploid grass carp were introduced in the reservoirs in multiple stockings at a target density of 20-30 carp per vegetated hectare (8-12/ac). Hydrilla coverage decreased from a 1994 peak of 17,272 hectares to only a few hectares in 1998. The grass carp population declined with the decrease in hydrilla coverage from 1992 to 1994 at a rate of 22% per year with a population size of 350,000 carp (17 carp per vegetated hectare) at the end of the survey period.

SUMMARY TABLE

Lake	Stocking Rate/Veg Ac	Hydrilla Targeted	Control Achieved
Anna	**20**	**Y**	**Y**
Ball	**5**	**N**	**P**
Carmel	**10**	**N**	**P**
Conway	**30**	**Y**	**Y**
Conroe	**>5**	**Y**	**Y**
Deer Point	**>9**	**N**	**Y**
Gaston	**6.5**	**Y**	**P**
Guntersville	**8**	**Y**	**P**
James	**42**	**Y**	**N**
Mahopac	**15**	**N**	**Y**
Norman	**0.5**	**Y**	**?**
Parkinson	**?**	**N**	**Y**
Santee Cooper	**8-12**	**Y**	**Y**

Y = Yes N= No P = Partial

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